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ONE
Science and Its Origins

WHAT IS SCIENCE?

The nature of science has been the subject of vigorous debate for centuries—a debate conducted by scientists, philosophers, historians, and other interested parties. Although no general consensus has emerged, several conceptions of science have attracted powerful support. (1) One view holds science to be the pattern of behavior by which humans have gained control over their environment. Science is thus associated with craft traditions and technology, and prehistoric people are regarded as having contributed to the growth of science when they learned how to work metals or engage in successful agriculture. (2) An alternative opinion *distinguishes* between science and technology, viewing science as a body of theoretical knowledge, technology as the application of theoretical knowledge to the solution of practical problems. On this view, the technology of automobile design and construction is to be distinguished from theoretical mechanics, aerodynamics, and the other theoretical disciplines that guide it; and only the theoretical disciplines are to count as "sciences."

Those who adopt this second approach, viewing science as theoretical knowledge, do not generally wish to concede that all theories (regardless of their character or content) are scientific; and for such people the task of definition has just begun. If they wish to exclude certain kinds of theories, they must propose criteria by which to judge one theory scientific and another unscientific. (3) It has become quite popular, therefore, to define science by the form of its statements—universal, law-like statements, preferably expressed in the language of mathematics. Thus Boyle's law (formulated by Robert Boyle in the seventeenth century) states that the pressure in a gas is inversely proportional to its volume if everything else remains constant. (4) If this seems too restrictive a criterion, science can be defined instead by its methodology. Science is thus associated with a particular set of procedures, usually experimental, for exploring nature's secrets and confirming or disconfirming theories about her behavior. A claim is therefore scientific if and only if it has an experimental foundation. (5) Such a definition, in turn, yields easily to attempts to define science by its epistemological status (that is, the kind of warrant its claims are held to possess) or even the tenacity with which its practitioners hold its doctrines. Thus Bertrand Russell has argued that "it is not *what* the man of science believes that distinguishes him, but *how* and *why* he believes it. His beliefs are tentative, not dogmatic; they are based on evidence, not on authority or intuition."[1] Science on this view is a privileged way of knowing and of justifying one's knowledge.

(6) In many contexts science is defined not by its methodology or epistemological status, but by its content. Science is thus a particular set of beliefs about nature—more or less the current teachings of physics, chemistry, biology, geology, and the like. By this test, belief in alchemy, astrology, and parapsychology is unscientific. (7) The terms "science" and "scientific" are often applied to any procedure or belief characterized by rigor, precision, or objectivity. Sherlock Holmes, according to this usage, adopted a scientific approach to the investigation of crime. (8) And finally, "science" and "scientific" are often simply employed as general terms of approval—epithets that we attach to whatever we wish to applaud.

What this brief and incomplete survey demonstrates is something that should perhaps have been obvious from the beginning—namely, that many words (including most of the interesting ones) have multiple meanings, varying with the particular context of usage. These meanings are sometimes mutually compatible and complementary, sometimes not. Moreover, it seems futile to attempt to eliminate diversity of usage. After all, language is not a set of rules grounded in the nature of the universe, but a set of conventions adopted by a group of people; and every meaning of the term "science" discussed above is a convention accepted by a sizable community, which is unlikely to relinquish its favored usage without a fight. Or to put the point in a slightly different way, lexicography must be pursued as a descriptive, rather than a prescriptive, art. We must acknowledge, therefore, that the term "science" has diverse meanings, each of them legitimate.

Even if we could find a definition of modern science that would satisfy everybody, the historian would still face a difficult problem. If the historian of science were to investigate past practices and beliefs only insofar as those practices and beliefs resemble modern science, the result would be a distorted picture. Distortion would be inevitable because science has changed in content, form, method, and function; and therefore the historian would not be responding to the past as it existed, but looking at the past through a grid that does not exactly fit. If we wish to do justice to the historical enterprise, we must take the past for what it was. And that means that we must resist the temptation to scour the past for examples or precursors of modern science. We must respect the way earlier generations approached nature, acknowledging that although it may differ from the modern way, it is nonetheless of interest because it is part of our intellectual ancestry. This is the only suitable way of understanding how we became what we are. The historian, then, requires a very broad definition of "science"—one that will permit investigation of the vast range of practices and beliefs that lie behind, and help us to understand, the modern scientific enterprise. We need to be broad and inclusive, rather than narrow and exclusive; and we should expect that the farther back we go, the broader we will need to be.[2]

This admonition is particularly important for anybody embarking on a study of the ancient and medieval worlds. If we were to restrict our attention to anticipations of modern science, we would be focusing on a very narrow range of activity, no doubt distorting it in the process, and overlooking many of the very beliefs and practices of ancient and medieval culture that should be the object of our study—those that will help us to understand the development, much later, of modern science.

I will do my best to heed my own advice in the pages that follow, adopting a definition of science as broad as that of the historical actors whose intellectual efforts we are attempting to understand. This does not mean, of course, that all distinctions are forbidden. I will distinguish between the craft and theoretical sides of science—a distinction that many ancient and medieval scholars would themselves have insisted upon—and I will focus my attention on the latter.[3] The exclusion of technology and the crafts from this narrative is not meant as a commentary on their relative importance, but rather as an acknowledgment of the magnitude of the problems confronting the history of technology and its status as a distinct historical specialty having its own skilled practitioners. My concern will be with the beginnings of scientific *thought,* and that will prove quite a sufficient challenge.

A final word about terminology. Up to now I have consistently employed the term "science." The time has come, however, to introduce the alternative expressions "natural philosophy" and "philosophy of nature," which will also appear frequently in this book. Why are these new expressions needed, and what are they meant to convey? The term "science" has connotations, both ancient and modern, that differentiate it somewhat (and in some contexts) from the subjects to which our investigation is directed. The modern term has all of the ambiguity sketched above, and the ancient terms (*scientia* in latin, *epistēmē* in Greek) were applicable to any system of belief characterized by rigor and certainty, whether or not it had anything to do with nature. It was thus common in the Middle Ages to refer to theology as a science (*scientia*). This book will explore ancient and medieval attempts to investigate *nature,* and the least ambiguous name for that enterprise was and is "natural philosophy" or "philosophy of nature."

But it is important that we not construe the use of these latter expressions as a demotion of the medieval investigation of nature from "scientific" to some lesser status. We would do well to remember that natural philosophy was the intellectual venture to which so important a scientific luminary as Isaac Newton (late seventeenth century) assigned his own work, entitling his great book on mechanics and gravitational theory *The Mathematical Principles of Natural Philosophy.* Natural philosophy, the investigation of nature, was conceived by Newton, as by his ancient and medieval predecessors, to be an integral part of the larger philosophical exploration of the total reality that humans confront.

In this book I will employ a diverse vocabulary, making practical concessions to the heterogeneity of customary usage. I will make regular use of the expression "natural philosophy," either to denote the scientific enterprise as a whole or to signify its more philosophical side. The term "science" will also be employed, most often as a synonym for "natural philosophy," sometimes to designate the more technical aspects of natural philosophy, and occasionally simply because conventional usage calls for that term in a certain context. There will be ample talk simply of "philosophy," for there is no hope of understanding natural philosophy if we ignore the larger enterprise to which it belonged. And, of course, I will make frequent reference to the subdisciplines of natural philosophy, the specific sciences: mathematics, astronomy, physics, optics, medicine, natural history, and the like. Careful attention to context should make the meaning clear in every case.

PREHISTORIC ATTITUDES TOWARD NATURE

From the beginning, the survival of the human race has depended on its ability to cope with the natural environment. Prehistoric people developed

impressive technologies for obtaining the necessities of life. They learned how to make tools, start fires, obtain shelter, hunt, fish, and gather fruits and vegetables. Successful hunting and food-gathering (and, after about 7000 or 8000 B.C., settled agriculture) required a substantial knowledge of animal behavior and the characteristics of plants. At a more advanced level, prehistoric people learned to distinguish between poisonous and therapeutic herbs. They developed a variety of crafts, including pottery, weaving, and metalworking. By 3500 they had invented the wheel. They were aware of the seasons and perceived the connection between the seasons and certain celestial phenomena. In short, they knew a great deal about their environment.

But the word "know," seemingly so clear and simple, is almost as tricky as the term "science"; indeed, it brings us back to the distinction between technology and theoretical science, discussed above. It is one thing to know how to do things, another to know why they behave as they do. One can engage in successful and sophisticated carpentry, for example, without any theoretical knowledge of stresses in the timbers one employs. An electrician with only the most rudimentary knowledge of electrical theory can successfully wire a house. It is possible to differentiate between poisonous and therapeutic herbs without possessing any biochemical knowledge that would explain poisonous or therapeutic properties. The point is simply that practical rules of thumb can be effectively employed even in the face of total ignorance of the theoretical principles that lie behind them. You can have "know-how" without theoretical knowledge.

It should be clear, then, that in practical or technological terms, the knowledge of prehistoric humans was great and growing. But what about theoretical knowledge? What did prehistoric people "know" or believe about the origins of the world in which they lived, its nature, and the causes of its numerous and diverse phenomena? Did they have any awareness of general laws or principles that governed the particular case? Did they even ask such questions? We have very little evidence on the subject. Prehistoric culture is by definition oral culture; and oral cultures, as long as they remain exclusively oral, leave no written remains. However, an examination of the findings of anthropologists studying preliterate tribes in the nineteenth and twentieth centuries, along with careful attention to remnants of prehistoric thought carried over into the earliest written records, will allow us to formulate a few tentative generalizations.

Critical to the investigation of intellectual culture in a preliterate society is an understanding of the process of communication. In the absence of writing, the only form of verbal communication is the spoken word; and the only storehouses of knowledge are the memories of individual members of the community. The transmission of ideas and beliefs in such a culture occurs only in face-to-face encounter, through a process that has been characterized as "a long chain of interlocking conversations" between its members. The portion of these conversations considered important enough to remember and pass on to succeeding generations forms the basis of an oral tradition, which serves as the principal repository for the collective experience and the general beliefs, attitudes, and values of the community.[4]

There is an important feature of oral tradition that demands our attention—namely, its fluidity. Oral tradition is typically in a continuous state of evolution, as it absorbs new experiences and adjusts to new conditions and needs within the community. Now this fluidity of oral tradition would be extremely perplexing if the function of oral tradition were conceived to be the communication of abstract historical or scientific data—the oral equivalent of a historical archive or a scientific report. But an oral culture, lacking the ability to write, certainly cannot create archives or reports; indeed, an oral culture lacks even the *idea* of writing and must therefore lack even the *idea* of a historical archive or a scientific report.[5] The primary function of oral tradition is the very practical one of explaining, and thereby justifying, the present state and structure of the community, supplying the community with a continuously evolving "social charter." For example, an account of past events may be employed to legitimate current leadership roles, property rights, or the present distribution of privileges and obligations. And in order to serve this function effectively, oral tradition must be capable of adjusting itself fairly rapidly to changes in social structure.[6]

But here we are principally interested in the *content* of oral traditions, especially those portions of the content that deal with the nature of the universe—the portions, that is, which might be thought of as the ingredients of a worldview or a cosmology. Such ingredients exist within every oral tradition, but often beneath the surface, seldom articulated, and almost never assembled into a coherent whole. It follows that we must be extremely reluctant to articulate the worldview of preliterate people on their behalf, for this cannot be done without *our* supplying the elements of coherence and system, thereby distorting the very conceptions we are attempting to portray. We may, nonetheless, formulate certain conclusions about the ingredients or elements of worldview within preliterate oral traditions. (The conclusions that follow are based on a mixture of evidence from prehistoric cultures and contemporary preliterate societies and, unless there is explicit warning to the contrary, should be taken to apply to both settings.)

It is clear that preliterate people, no less than those of us who live in a modern scientific culture, have a need for explanatory principles capable of bringing order, unity, and especially meaning to the apparently random and chaotic flow of events. But we should not expect the explanatory principles accepted by preliterate people to resemble ours: lacking any conception of "laws of nature" or deterministic causal mechanisms, their ideas of causation extend well beyond the sort of mechanical or physical action acknowledged by modern science. It is natural that in the search for meaning they should proceed within the framework of their own experience, projecting human or biological traits onto objects and events that seem to us devoid not only of humanity but also of life. Thus the beginning of the universe is typically described in terms of birth, and cosmic events may be interpreted as the outcome of struggle between opposing forces, one good and the other evil. There is an inclination in preliterate cultures not only to personalize but also to individualize causes, to suppose that things happen as they do because they have been willed to do so. This tendency has been described by H. and H. A. Frankfort:

> Our view of causality . . . would not satisfy primitive man because of the impersonal character of its explanations. It would not satisfy him, moreover, because of its generality. We understand phenomena, not by what makes them peculiar, but by what makes them manifestations of general laws. But a general law cannot do justice to the individual character of each event. And the individual character of the event is precisely what early man experiences most strongly. We may explain that certain physiological processes cause a man's death. Primitive man asks: Why should *this* man die *thus* at *this* moment? We can only say that, given these conditions, death will always occur. He wants to find a cause as specific and individual as the event which it must explain. The event . . . is experienced in its complexity and individuality, and these are matched by equally individual causes.[7]

Oral traditions typically portray the universe as consisting of sky and earth, and perhaps also an underworld. An African myth describes the earth as a mat that has been unrolled but remains tilted, thereby explaining upstream and downstream—an illustration of the general tendency to describe the universe in terms of familiar objects and processes. Deity is an omnipresent reality within the world of oral traditions, though in general no clear distinction is drawn between the natural, the supernatural, and the human; the gods do not transcend the universe but are rooted in it and subject to its principles. Belief in the existence of ghosts of the dead, spirits, and a variety of invisible powers, which magical ritual allows one to control, is another universal feature of oral tradition. Reincarnation (the idea that after death the soul returns in another body, either human or animal) is widely believed in. Conceptions of space and time are not (like those of modern physics) abstract and mathematical, but are invested with meaning and value drawn from the experience of the community. For example the cardinal directions for a community whose existence is closely connected to a river might be "upstream" and "downstream," rather than north, south, east, and west. Some oral cultures have difficulty conceiving of more than a very shallow past: an African tribe, the Tio, for example, cannot situate anybody farther back in time than two generations.[8]

There is a strong tendency within oral traditions to identify causes with beginnings, so that to explain something is to identify its historical origins. Within such a conceptual framework, the distinction that we make between scientific and historical understanding cannot be sharply drawn and may be nonexistent. Thus when we look for the features of oral tradition that count for worldview or cosmology, they will almost always include an account of origins—the beginning of the world, the appearance of the first humans, the origin of animals, plants, and other important objects, and finally the formation of the community. Related to the account of origins is often a genealogy of gods, kings, or other heroic figures in the community's past, accompanied by stories about their heroic deeds. It is important to note that in such historical accounts the past is portrayed not as a chain of causes and effects that produce gradual change, but as a series of decisive, isolated events, by which the present order came into existence.[9]

These tendencies can be illustrated with examples from both ancient and contemporary oral cultures. According to the twentieth-century Kuba of equatorial Africa,

> Mboom or the original water had nine children, all called Woot, who in turn created the world. They were, apparently in order of appearance: Woot the ocean; Woot the digger, who dug riverbeds and trenches and threw up hills; Woot the flowing, who made rivers flow; Woot who created the woods and savannas; Woot who created the leaves; Woot who created the stones; Woot the sculptor, who made people out of wooden balls; Woot the inventor of prickly things such as fish, thorns, and paddles; and Woot the sharpener, who first gave an edge to pointed things. Death came to the world when a quarrel between the last two Woots led to the demise of one of them by the use of a sharpened point.[10]

Notice how this tale not only accounts for the origin of the human race and the major topographical features of the Kuba world, but also explains the invention of what the Kuba clearly considered a critically important tool—the sharpened object.

Similar themes abound in early Egyptian and Babylonian creation myths. According to one Egyptian account, in the beginning the sun-god, Atum, spat out Shu, the god of air, and Tefnut, the goddess of moisture. Thereafter,

> Shu and Tefnut, air and moisture, gave birth to earth and sky, the earth-god Geb and the sky-goddess Nut. . . . Then in their turn Geb and Nut, earth and sky, mated and produced two couples, the god Osiris and his consort Isis, the god Seth and his consort Nephthys. These represent the creatures of this world, whether human, divine, or cosmic.[11]

A Babylonian myth attributes the origin of the world to the sexual activity of Enki, god of the waters. Enki impregnated the goddess of the earth or soil, Ninhursag. This union of water and earth gave rise to vegetation, represented by the birth of the goddess of plants, Ninsar. Enki subsequently mated first with his daughter, then with his granddaughter, to produce various specific plants and plant products. Ninhursag, angered when Enki devoured eight of the new plants before she had the opportunity to name them, pronounced a curse on him. Fearing the consequences of Enki's demise (apparently the drying up of the waters), the other gods prevailed on Ninhursag to withdraw the curse and heal Enki of the various ailments induced by the curse, which she did by giving birth to eight healing deities, each associated with a part of the body—thus accounting for the origin of the healing arts.[12]

It will be convenient to pause for a moment on the healing arts, which can serve to illustrate some of the characteristics of oral cultures. There can be no doubt that healing practices were extremely important in ancient oral cultures, where primitive conditions made disease and injury everyday realities.[13] Minor medical problems, such as wounds and lesions, were no doubt treated by family members. More dramatic ailments—

major wounds, broken bones, severe and unexpected illness—might require assistance from somebody with more advanced knowledge and skill. A certain amount of medical specialization thus came into existence: some members of the tribe or the village became known for their herb-gathering ability, their proficiency in the setting of bones or the treatment of wounds, or their experience in assisting at childbirth.

But so described, the primitive medicine practiced in preliterate societies sounds remarkably like a rudimentary version of modern medicine. A more careful look reveals the healing arts within oral cultures to be inseparable and indistinguishable from religion and magic. The wise woman or the "medicine man" was valued not simply for pharmaceutical or surgical skill, but also for knowledge of the divine and demonic causes of disease and the magical and religious rituals by which it could be treated. If the problem was a splinter, a wound, a familiar rash, a digestive complaint, or a broken bone, the healer responded in the obvious way—by removing the splinter, binding the wound, applying a substance (if one were known) that would counteract the rash, issuing dietary prohibitions, and setting and splinting the broken limb. But if a family member became mysteriously and gravely ill, one might suspect sorcery or invasion of the body by an alien spirit. In such cases, more dramatic remedies would be called for—exorcism, divination, purification, songs, incantations, and other ritualistic activities.

There is one last feature of belief in oral cultures (both ancient and contemporary) that demands our attention—namely, the simultaneous acceptance of what seem to us incompatible alternatives, without any apparent awareness that such behavior could present a problem. Examples are innumerable, but it may suffice to note that the story of the nine Woots related above is one of seven (or more) myths of origin that circulate among the Kuba, while the Egyptians had a variety of alternatives to the story of Atum, Shu, Tefnut, and their offspring; and nobody seems (or seemed) to notice, or else to care, that all of them could not be true. Add to this the seemingly "fanciful" nature of many of the beliefs described above, and we inevitably raise the question of "primitive mentality": do the members of preliterate societies possess a mentality that is prelogical or mystical or in some other way different from our own; and, if so, exactly how is this mentality to be described and explained?[14]

This is an extremely complex and difficult problem, which has been hotly debated by anthropologists and others for the better part of the twentieth century, and I am not likely to resolve it here. But I can at least offer a word of methodological advice: namely, that it is wasted effort, contributing absolutely nothing to the cause of understanding, to spend time wishing that preliterate people would employ (or had employed) a conception and criteria of knowledge that they have (or had) never encountered—a conception, in the case of prehistoric people, that was not invented until centuries later. We make no progress by assuming that preliterate people were trying, but failing, to live up to our conceptions of knowledge and truth. It requires only a moment of reflection to realize that they must have been operating within quite a different linguistic and conceptual world, and with different purposes; and it is in the light of these that their achievements must be judged.

The stories embodied in oral traditions are intended to convey and reinforce the values and attitudes of the community, to offer satisfying explanations of the major features of the world as experienced by the community, and to legitimate the current social structure; stories enter the oral tradition (the collective memory) because of their effectiveness in achieving those ends, and as long as they continue to do so there is no reason to question them. There are no rewards for skepticism in such a social setting and few resources to facilitate challenge. Indeed, our highly developed conceptions of truth and the criteria that a claim must satisfy in order to be judged true (internal coherence, for example, or correspondence with an external reality) do not generally exist in oral cultures and, if explained to a member of an oral culture, would probably seem quite useless. Rather, the operative principle among preliterates is that of sanctioned belief—the sanction in question emerging from community consensus.[15]

Finally, if we are to understand the development of science in antiquity and the Middle Ages, we must ask how the preliterate patterns of belief that we have been examining yielded to, or were supplemented by, a new conception of knowledge and truth (represented most clearly in the principles of Aristotelian logic and the philosophical tradition it spawned). The decisive development seems to have been the invention of writing, which occurred in a series of steps. First there were pictographs, in which the written sign stood for the object itself. Around 3000 B.C. a system of word signs (or logograms) appeared, in which signs were created for the important words, as in Egyptian hieroglyphics. But in hieroglyphic writing, signs could also stand for sounds or syllables—the beginnings of syllabic writing. The development of fully syllabic systems about 1500 B.C. (that is, systems in which all nonsyllabic signs were discarded) made it possible and, indeed, reasonably easy for people to write down everything they could say. And finally fully alphabetic writing, which has a sign for each sound (both consonants and vowels), made its appearance in Greece about 800 B.C. and became widely disseminated in Greek culture in the sixth and fifth centuries.[16]

One of the critical contributions of writing, especially alphabetic writing, was to provide a means for the recording of oral traditions, thereby freezing what had hitherto been fluid, translating fleeting audible signals into enduring visible objects.[17] Writing thus served a storage function, replacing memory as the principal repository of knowledge. This had the revolutionary effect of opening knowledge claims to the possibility of inspection, comparison, and criticism. Presented with a written account of events, we can compare it with other (including older) written accounts of the same events, to a degree unthinkable within an exclusively oral culture. Such comparison encourages skepticism and, in antiquity, helped to create the distinction between truth, on the one hand, and myth or legend, on the other; that distinction, in turn, called for the formulation of criteria by which truthfulness could be ascertained; and out of the effort to formulate suitable criteria emerged rules of reasoning, which offered a foundation for serious philosophical activity.[18]

But giving permanent form to the spoken word does not merely encourage inspection and criticism. It also makes possible new kinds of intellectual activity that have no counterparts (or only weak ones) in an oral culture. Jack Goody has argued convincingly that early literate cultures produced large quantities of written inventories and other kinds of lists (mostly for administrative purposes), far more elaborate than anything an oral culture could conceivably produce; and, moreover, that these lists made possible new kinds of inspection and called for new thought processes or new ways of organizing thoughts. For one thing, the items in a list are removed from the context that gives them meaning in the world of oral discourse, and in that sense they have become abstractions. And in this abstract form they can be separated, sorted, and classified according to a variety of criteria, thereby giving rise to innumerable questions not likely to be raised in an oral culture. To give a single example, the lists of precise celestial observations assembled by early Babylonians could never have been collected and transmitted in oral form; their existence in writing, which allowed them to be minutely examined and compared, made possible the discovery of intricate patterns in the motions of the celestial bodies which we associate with the beginnings of mathematical astronomy and astrology.[19]

Two conclusions may be drawn from this argument. First, the invention of writing was a prerequisite for the development of philosophy and science in the ancient world. Second, the degree to which philosophy and

science flourished in the ancient world was, to a very significant degree, a function of the efficiency of the system of writing (alphabetic writing having a great advantage over all of the alternatives) and the breadth of its diffusion among the people. We see the earliest benefits of the use of word signs or logograms in Egypt and Mesopotamia, beginning about 3000 B.C. However, the difficulty and inefficiency of logographic writing inevitably limited its diffusion and made it the property of a small scholarly elite. In sixth- and fifth-century Greece, by contrast, the wide dissemination of alphabetic writing contributed to the spectacular development of philosophy and science. We must not imagine that literacy was sufficient of itself to produce the "Greek miracle" of the sixth and fifth centuries; other factors no doubt contributed, including prosperity, new principles of social and political organization, contact with Eastern cultures, and the introduction of a competitive style into Greek intellectual life. But surely the most important element in the mix was the emergence of Greece as the world's first widely literate culture.[20]

THE BEGINNINGS OF SCIENCE IN EGYPT AND MESOPOTAMIA

I will turn to the Greek world in the next chapter. Before doing so, I must touch briefly on pre-Greek developments in Egypt and Mesopotamia (the region between the Tigris and Euphrates rivers, site of ancient Babylonia and Assyria and of modern Iraq—see map 2). I have said enough about creation myths in the preceding section to reveal key features of Egyptian and Mesopotamian cosmological and cosmogonical speculation. Here I will restrict myself to the Egyptian and Mesopotamian contribution to several other subjects or disciplines that subsequently found a place within Greek and medieval European science: mathematics, astronomy, and medicine. The evidence is scanty but sufficient to convey a general picture.

The Greeks themselves believed that mathematics originated in Egypt and Mesopotamia. Herodotus (fifth century B.C.) reported that Pythagoras traveled to Egypt, where he was introduced by priests to the mysteries of Egyptian mathematics. From there, according to ancient tradition, he was carried captive to Babylon, where he came into contact with Babylonian mathematics. Eventually he made his way home to the island of Samos, bearing Egyptian and Babylonian mathematical treasure to the Greeks. Whether this and similar tales regarding other mathematicians are historically accurate or legendary is less important than the larger truth they convey—namely, that the Greeks were (and knew they were) the recipients of Egyptian and Babylonian mathematical knowledge.

By about 3000 B.C., the Egyptians developed a number system that was decimal in character, employing a different symbol for each power of 10 (1, 10, 100, and so forth). These symbols could be lined up, as in Roman numerals, to form any desired number. Thus if I represented 1, and ∩ represented 10, then the number 34 could be expressed as IIII∩∩∩. By about 1800 B.C. additional symbols had been devised for other numbers, so that, for example, 7 could be represented by a sickle (ʔ) rather than by seven vertical strokes. Addition and subtraction were simple operations in Egyptian arithmetic, performed as with Roman numerals, but multiplication and division were extremely clumsy; and the generalized concept of a fraction was unknown, the general rule allowing only unit fractions (fractions with a numerator of 1). Elementary problems of the following type could be solved: if one-seventh of a quantity is added to the quantity, and the sum equals 16, how large is the quantity?[21]

Egyptian geometrical knowledge seems to have been oriented toward practical problems, perhaps those of surveyors and builders. Egyptians were able to calculate the areas of simple plane figures, such as the triangle and the rectangle, and the volumes of simple solids, such as the pyramid. For example, to find the area of a triangle they took one-half the length of the base times the altitude; and, to find the volume of a pyramid, one-third the area of the base times the altitude. For calculating the area of a circle, the Egyptians worked out rules that correspond to a value for π of about 3.17. Finally, in one of the most obvious areas of applied mathematics, the Egyptians devised an official calendar consisting of twelve months of thirty days each, plus an additional five days at the end of the year—a calendar substantially simpler, because of its fixed character, than contemporary Babylonian calendars and those of the early Greek city-states, which attempted to take into account the lunar, as well as the solar, cycle.[22]

The contemporary mathematical achievement in Mesopotamia was an order of magnitude superior to that of the Egyptians. Clay tablets (see fig. 1.1) recovered in large quantities reveal a Babylonian number system, fully developed by about 2000 B.C., that was simultaneously decimal (based on the number 10) and sexagesimal (based on the number 60). We retain sexagesimal numbers today in our system for measuring time (sixty minutes to an hour) and angles (sixty minutes in a degree and 360 degrees in a circle). The Babylonians had separate symbols for 1 (▼) and 10 (◀); these could be combined like Roman numerals to form numbers up to 59. The number 32, for example, would be expressed by three of the tens symbol plus two of the units symbol, as in table 1.1.

But beyond 59 an important difference appears. Instead of forming the

Fig. 1.1. A Babylonian clay tablet (ca. 1900–1600 B.C.), containing a mathematical problem text dealing with bricks, their volumes, and their coverage. Yale Babylonian Collection, YBC 4607. The text is translated and discussed in O. Neugebauer and A. Sachs, eds., *Mathematical Cuneiform Texts,* pp. 91–97.

Table 1.1. Five Babylonian Sexagesimal Numbers and Their Hindu-Arabic equivalents.

	60^3	60^2	60	1	1/60	$1/60^2$	Modern Hindu-Arabic Equivalent
(1)				◀◀◀▼▼			32
(2)			▼▼	◀▼▼▼▼▼▼			2×60 + 16 = 136
(3)		▼	◀▼▼	◀◀▼▼▼			1×3600 + 12×60 + 23 = 4,343
(4)	▼▼	◀◀▼▼					2×216000 + 22 × 3600 = 511,200
(5)					◀◀	◀▼▼	2×1/60 + 12×1/3600 = 1/30 + 1/300 = 11/300

▼ = 1 ◀ = 10

number 60 by lining up six symbols for 10, the Babylonians used a place system similar to our own. In our number 234, the numeral 4 (situated in the "units column") signifies simply the number 4; the numeral 3, situated in the tens column represents the number 30; while the numeral 2, situated in the hundreds column stands for the number 200. Thus 234 is 200 + 30 + 4. The Babylonian place system worked similarly, except that successive columns represent powers of 60 rather than powers of 10. Thus in the second example in table 1.1, the two unit symbols in the sixties column represent not 2, but $2\times60=120$; and in the third example the unit symbol in the 60^2 column represents not 1 but $1\times60^2=3{,}600$. There was no equivalent of the decimal point by which to locate the units column, and this information would therefore have to be inferred from context. Multiplication tablets, tables of reciprocals, and tables of powers and roots were used to facilitate calculation. One of the great advantages of the sexagesimal system was the ease with which calculations could be performed using fractions.[23]

The full superiority of Babylonian mathematics over its Egyptian counterpart is evident when we turn to more difficult problems, which *we* would solve algebraically. Historians of mathematics sometimes refer to these problems as "algebra," useful shorthand for this aspect of the Babylonian mathematical enterprise, perhaps, but dangerous if it is taken to mean that they practiced genuine algebra—that is, that they had a generalized algebraic notation or an understanding of what we consider algebraic rules. What we can safely say is that Babylonian mathematicians used arithmetical operations to solve problems for which *we* would employ a quadratic equation. For example, we find many Babylonian tablets, including teaching texts, demonstrating how to solve problems such as the following: given the product of two numbers and their sum or difference, find the two numbers.[24]

One of the areas to which Babylonians applied their mathematical techniques was astronomy. The stars have been objects of investigation and speculation since earliest times. Some of our oldest written records, going back more than 4,000 years, are astronomical in character. There were several reasons for this interest in the heavens. One was agricultural, for it was obvious even from fairly casual observation that the agricultural seasons—the times for planting and harvesting—correspond to the motion of the sun and the position of certain stars and constellations in relation to the sun. A second reason was religious, for the heavens, especially the sun and moon, were usually associated with divinity. A third was astrological. And a fourth was calendric.

Some of the earliest effort was devoted to mapping the heavens—identifying and naming prominent stars and constellations, observing their relationships, and linking their visibility to the seasons. In Mesopotamia, systematic astronomical observation came to be practiced in the temples, for religious, astrological, and calendric purposes. Temple priests not only mapped the fixed stars but also identified the "wandering stars" or planets—the planets now named Mercury, Venus, Mars, Jupiter, and Saturn. (The sun and moon were also considered planets, because they too moved in relation to the fixed stars.) These seven planets were observed to move slowly through the heavens within the narrow band of the zodiac. By about 500 B.C. Babylonian priests had defined this band and identified the constellations that mark it off into twelve segments of thirty degrees each, thus giving us the signs of the zodiac. Once defined, the zodiac could function as a handy measuring system for charting the exact motions of the sun, moon, and remaining planets, and as a source of astrological predictions.[25]

The astrological aspect of Babylonian astronomy requires brief mention (on astrology, see also below, chap. 11). It is clear that astrological needs were a major motivation for the development of Babylonian mathematical astronomy. Out of astral religion—the association of the stars (specifically the wandering stars) with the gods—and the obvious fact that celestial events were connected with the seasons and the weather, there developed a system of judicial astrology, the attempt to make short-term predictions affecting the king and the kingdom on the basis of the current celestial configuration. It is also possible that horoscopic astrology, which predicts the course of a person's life from the celestial configuration at the time of birth, developed in the late Babylonian period. What is important is that both kinds of astrology called for detailed knowledge of solar, lunar, and the other planetary motions. Babylonian astrology was transmitted to the Greeks, who further developed it and passed it on to the Middle Ages, the early modern period, and ultimately the twentieth century. Through most of that long history, it should be noted, the astronomical and astrological traditions have been intimately linked.[26]

We do not have space to examine the development of Babylonian mathematical astronomy in detail. What is important is that in the period 500–300 B.C., the Babylonian astronomer-priest developed his art to the point where he could manipulate large quantities of astronomical data and make a variety of astronomical predictions. He had numerical models, in the form of arithmetic progressions, that enabled him to chart the daily motions of the sun and moon through the zodiac. From such data he could predict the first appearance of the new moon (important for the calendar, since the new moon signified the beginning of a new month); he could also predict lunar eclipses and the possibility or impossibility of solar eclipses. We must stress that he did this not by the use of geometrical models, as Greek astronomers would do, but simply through the use of numerical methods that extrapolated past observations into the future.[27]

The final area of Egyptian and Mesopotamian achievement to be considered is medical. A number of Egyptian medical papyri (written in the period 2500–1200 B.C.) have survived, and these offer us a fragmentary picture of the healing arts in ancient Egypt. From several of the papyri it becomes clear that a principal cause of disease was thought to be invasion of the body by evil forces or spirits. Relief was to be gained through rituals designed to appease or frighten the spirits—exorcism, incantation, purification, or the wearing of an appropriate amulet. The gods could be appealed to for protection: a prayer to the god Horus, found in the Leyden papyrus, reads in part, "Hail to thee, Horus . . . . I come to thee, I praise thy beauty: destroy thou the evil that is in my limbs."[28] Certain gods came especially to be associated with healing functions or healing cults: Thoth, Horus, Isis, and Imhotep. The view that each bodily organ was ruled by a specific god, who could be invoked for healing of that organ, seems to have been widespread. And all of this ritual, of course, required the assistance of an expert who was of acknowledged purity, who knew the required incantations, and who could assure that the ritual was properly performed to the smallest detail; this was the priest-healer.

Healing therapies in ancient Egypt were not limited to prayer, incantation, and ritual. Pharmacological remedies, prepared from animal, vegetable, or mineral substances, were also widespread—though their effectiveness was believed to be conditional on having been prepared and administered under appropriate ritual conditions. The Ebers papyrus (written about 1600 B.C., but containing material copied from much older texts) contains medical recipes for dealing with diseases of the skin, eyes, mouth, extremities, digestive and reproductive systems, and other internal organs; for treating wounds, burns, abscesses, ulcers, tumors, headaches, swollen glands, and bad breath.[29]

Surgery is dealt with in another papyrus, known as the Edwin Smith papyrus (written about the same time as the Ebers papyrus), which contains a surgical manual that systematically describes the treatment of wounds, fractures, and dislocations (see fig. 1.2).[30] One of the notable features of the Ebers and Edwin Smith papyri is the careful arrangement of case studies, beginning with a description of the problem and proceeding to diagnosis, verdict (as to whether or not the ailment is treatable), and treatment.

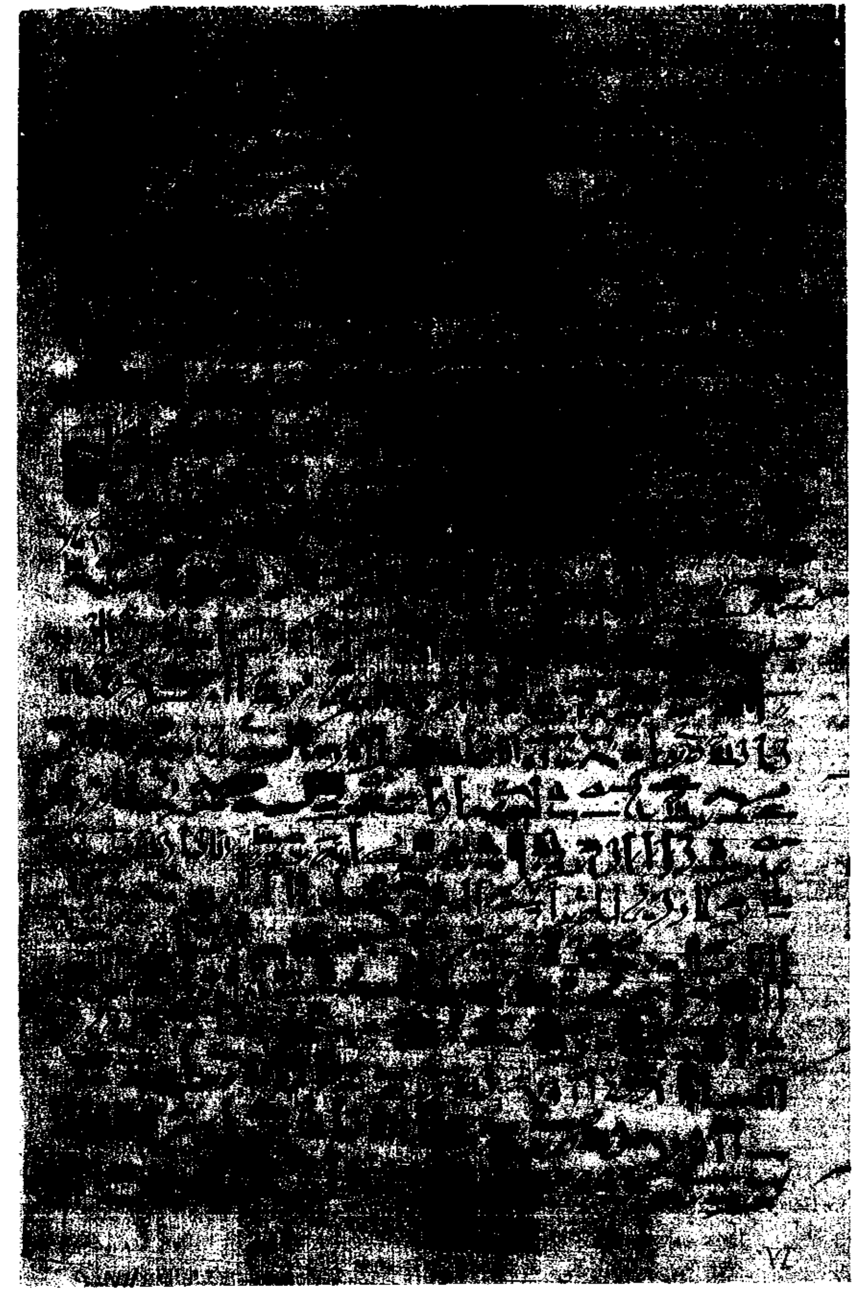


Fig. 1.2. A column from the Edwin Smith Surgical Papyrus (ca. 1600 B.C.), now in the New York Academy of Medicine.

Mesopotamian medicine displays many of the same characteristics as Egyptian healing practices. Babylonian clay tablets, like Egyptian papyri, contain case studies, systematically organized by type, many of them revealing careful observation of symptoms and intelligent prognosis. Mesopotamian healers displayed equal skill in surgery and the preparation of pharmaceutical remedies. As in Egypt, a certain amount of medical specialization developed—different categories of healers coming to have somewhat different specialties and functions. And again we find healing intimately mingled with religion and with practices that we would now view as magical. Disease was regarded as the result of invasion of the body by evil spirits (owing to fate, carelessness, sin, or sorcery). Therapy was directed toward elimination of the invading spirit through divination (including the interpretation of astrological omens), sacrifice, prayer, and magical ritual.[31]

This brief sketch of Egyptian and Mesopotamian contributions to mathematics, astronomy, and the healing arts offers us a glimpse of the beginnings of the Western scientific tradition, as well as a context within which to view the Greek achievement. There is no doubt that the Greeks were aware of the work of their Egyptian and Mesopotamian predecessors, and profited from it. In the chapters that follow, we will see how these products of Egyptian and Mesopotamian thought entered and helped shape Greek natural philosophy.

TWO
The Greeks and the Cosmos

THE WORLD OF HOMER AND HESIOD

We know nothing of Homer, reputed author of two great epic poems, the *Iliad* and the *Odyssey*. The poems, which recount heroic adventures associated with the closing days and aftermath of the Trojan War between the Greeks and Troy, are clearly the products of a long oral tradition, having roots that go far back in Greek history to the Mycenean age (before 1200); they appear also to have been influenced by non-Greek epic traditions from the Near East. They were perhaps committed to writing in the eighth century, but whether by one man (Homer) or several remains a matter of dispute. Whatever their precise origin, the *Iliad* and *Odyssey* became the foundation of Greek education and culture and remain among the best measures we have of the form and content of ancient Greek thought.[1]

Alongside Homer we must place Hesiod, who flourished around the end of the eighth century. To Hesiod, the son of a farmer, two major poetic works are attributed: *Works and Days* (which includes, among other things, a manual of farming) and the *Theogony*, which recounts the origin of the gods and the world.[2] Hesiod gave the gods a genealogy and, together with Homer, defined their character and the functions over which they presided. It was through the joint influence of Homer and Hesiod that the twelve gods of Mount Olympus were chosen from a plethora of local deities to become the gods of the Greeks.

Among the Olympians was Zeus, portrayed by Homer and Hesiod as the greatest and most powerful of the gods, lord of the sky, god of weather, wielder of lightning bolts, upholder of law and morality, and father of all. Hera, his sister and wife, presided over weddings and marriage. Poseidon, brother of Zeus, was god of both sea and earth, author of storms and earthquakes. Hades, another brother, was lord of the underworld and

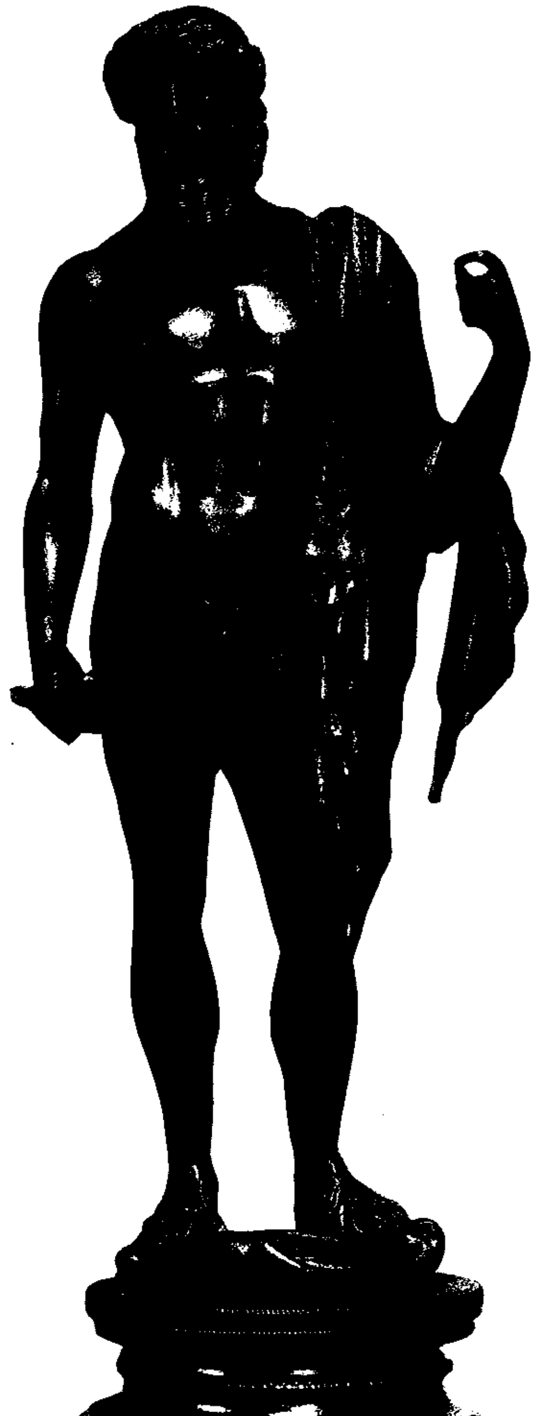


Fig. 2.1. A bronze statue of Zeus in the Museo Archeologico, Florence. Alinari/Art Resource N.Y.

the dead. Athena, daughter of Zeus, was the goddess of warfare and the protector of cities, while Ares, son of Zeus, was the ruthless god of war.

In Homer's portrayal, the gods were intimately involved in human affairs, determining victory, defeat, misfortune, and destiny. Various instances of divine involvement appear in the *Odyssey*. Its hero, Odysseus, shipwrecked as a result of divine wrath and confined for eight years on the island of the nymph Calypso, was finally released from imprisonment at Zeus's command and set sail for Ithaca. However, Poseidon, who had not been consulted on the release of Odysseus, spotted him on his raft and decided to interfere:

> With that he gathered the clouds and troubled the waters of the deep, grasping his trident in his hands; and he roused all storms of all manner of winds, and shrouded in clouds the land and sea: and down sped night from heaven. . . . Poseidon, shaker of the earth, stirred against him a great wave, terrible and grievous, and vaulted from the crest, and therewith smote him.

And so Odysseus made his way home, sometimes aided, sometimes thwarted by the gods.[3]

In Hesiod's *Theogony* we find a brief history of the world, from primeval chaos to the orderly rule of Zeus. From chaos arose Gaia ("broad-bosomed earth") and various other offspring, including Eros (love), Erebos (a part of the underworld), and darkest Night. Erebos and Night mated to produce Day and Aither (or sky). Gaia first bore the starry heaven (Ouranos) "to cover her everywhere over and be an ever-immovable base for the gods who are blessed. And she bore the high mountains, the charming retreats of the goddess nymphs who have their abodes in the wooded glens of the mountains. And . . . she brought forth Pontos, the exhaustless sea that rages and waves."[4] Gaia (mother earth) proceeded to mate with her offspring, Ouranos (father heaven), and from that union issued Oceanus (the river that encircles the world, father of all other rivers), the twelve Titans, and a collection of monsters. Eventually Kronos, one of the Titans, castrated and otherthrew his father, Ouranos; Kronos, in turn, was deposed by his son Zeus. Zeus obtained the thunderbolt from the Cyclopes and used it to defeat the Titans and establish his own Olympian rule.

Even this brief description reveals the chasm separating the world of Homer and Hesiod from that of modern science. Theirs was a world of anthropomorphic deities interfering in human affairs and using humans as

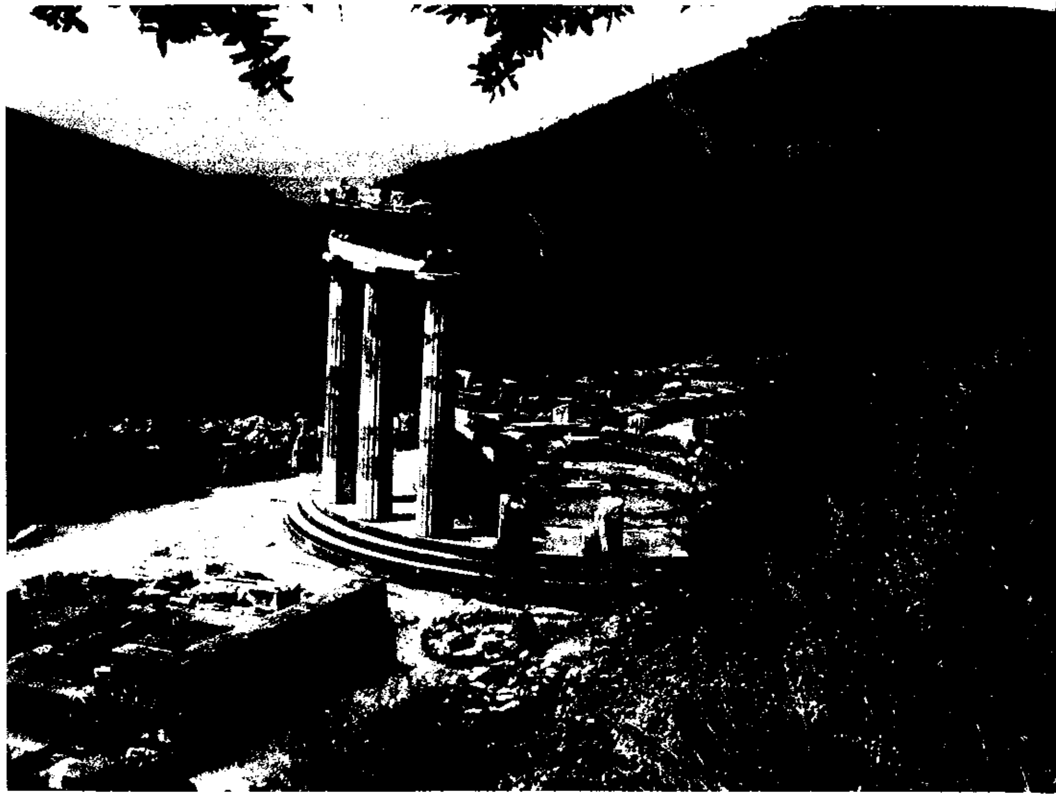


Fig. 2.2. A shrine to the earth goddess Gaia at Delphi (4th century B.C.).

pawns in their own plots and intrigues. This was inevitably a capricious world, in which nothing could be safely predicted because of the boundless possibilities of divine intervention. Natural phenomena were personified and divinized. Sun and moon were conceived as deities, offspring of the union of Theia and Hyperion. Storms, lightning bolts, and earthquakes were not considered the inevitable outcome of impersonal, natural forces, but mighty feats, willed by the gods.

What are we to make of this? Did the ancient Greeks take the stories constituting what we now call "Greek mythology" to be true? Did they really believe in divine beings, lodged on Mount Olympus or in some other mysterious place, seducing one another and bedeviling the humans who crossed their path? Did nobody doubt that storms and earthquakes were a result of divine caprice? We have seen in the previous chapter, in the discussion of preliterate thought, how difficult these questions are.[5]

What is clear is that any attempt to measure such beliefs by modern criteria of scientific truth is a sure road to misunderstanding. We can, however, learn something from a glance at contemporary beliefs outside the scientific realm. When a political candidate, military commander, or professional athlete thanks God for victory, does he or she really believe that victory was supernaturally obtained? The answer is not entirely clear, and probably varies from case to case. What seems certain is that the public figures in question are not attempting to deal with causal questions in a philosophical or scientific manner, and it has probably never occurred to them that their assertions might be judged by philosophical or scientific criteria. By the same token, although the works of Homer and Hesiod seem to address questions of causation, we must understand that they were not intended as scientific or philosophical treatises. Homer and Hesiod—and the bards whose epic poems lie behind theirs—were recording heroic deeds in order to instruct and entertain; and if we treat them as failed philosophers, we will inevitably misunderstand their achievement.

Yet we must not dismiss these ancient sources too quickly. Homer and Hesiod, after all, are among the few sources at our disposal that reveal *anything* of archaic Greek thought; and if they do not represent primitive Greek philosophy, they were nonetheless central to Greek education and culture for centuries and cannot have been without influence on the Greek mind. It is abundantly clear that the language and the images people employ affect the reality they perceive. If the content of Homer's and Hesiod's poems was not "believed" in the same way as we believe the content of modern physics, the mythology of the Olympian gods (not to speak of the mythology of local deities) was nonetheless a central feature of Greek culture, affecting the way Greeks thought, talked, and behaved.

THE FIRST GREEK PHILOSOPHERS

Early in the sixth century, Greek philosophy made its first appearance. This was not, as some have portrayed it, the replacement of mythology by philosophy; for Greek mythology did not disappear but continued to flourish for centuries. Rather, it was the appearance of new, philosophical modes of thought alongside, or sometimes mingled with, mythology. Simply put, Homer and Hesiod were not philosophers and did not practice philosophy; Thales, Pythagoras, and Heraclitus, while living in a culture still rife with mythology, undertook a new kind of intellectual inquiry, which we are prepared to call "philosophy."

But what were the new modes of thought that we identify as philosophy?

A group of thinkers in the sixth century initiated a serious, critical inquiry into the nature of the world in which they lived—an inquiry that has stretched from their day to ours. They asked about its ingredients, its composition, and its operation. They inquired whether it is made of one thing or many. They asked about its shape and location and speculated about its origins. They sought to understand the process of change, by which things come into being and one thing seems to be transformed into another. They contemplated extraordinary natural phenomena, such as earthquakes and eclipses, and sought universal explanations applicable not only to a particular earthquake or eclipse but to earthquakes and eclipses in general. And they began to reflect on the rules of argumentation and proof.

The early philosophers did not merely pose a new set of questions; they also sought new kinds of answers. Personification of nature gradually became a less prominent feature of their discourse, and the gods disappeared from their explanations of natural phenomena. We have seen the mythological approach of Homer and Hesiod: in Hesiod's *Theogony* earth and sky are regarded as divine offspring. In Leucippus and Democritus, by contrast, the world and its various parts result from the mechanical sorting of atoms in the primeval vortex. As late as the fifth century, the historian Herodotus retained much of the old mythology, sprinkling tales of divine intervention through his *Histories*. Poseidon, by his account, used a high tide to flood a swamp the Persians were crossing. And Herodotus regarded an eclipse that coincided with the departure of the Persian army for Greece as a supernatural omen. The philosophers offered a quite different account of floods and eclipses, containing no hint of supernatural intervention. Anaximander judged eclipses to be the result of blockage of the apertures in rings of celestial fire. According to Heraclitus, the heavenly bodies are bowls filled with fire, and an eclipse occurs when the open side of a bowl turns from us. The theories of Anaximander and Heraclitus do not seem particularly sophisticated (fifty years after Heraclitus the philosophers Empedocles and Anaxagoras understood that eclipses were caused simply by cosmic shadows), but what is of critical importance is that they exclude the gods. The explanations are entirely naturalistic; eclipses do not reflect personal whim or the arbitrary fancies of the gods, but simply the nature of fiery rings or of celestial bowls and their fiery contents.[6]

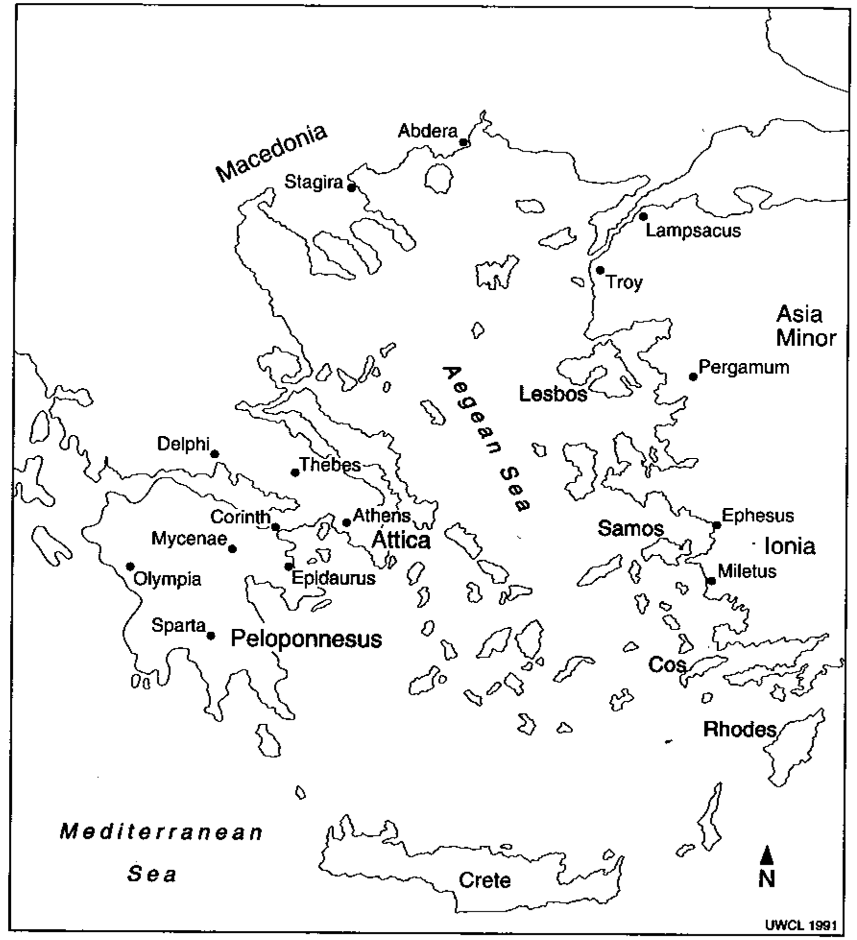
The world of the philosophers, in short, was an orderly, predictable world in which things behaved according to their natures. The Greek term used to denote this ordered world was *kosmos*, from which we draw our word "cosmology." The capricious world of divine intervention was being pushed aside, making room for order and regularity; *kosmos* was being substituted for *chaos*. A distinction between the natural and the supernatural was emerging; and there was wide agreement that causes (if they are to be dealt with philosophically) are to be sought only in the nature of things. The philosophers who introduced these new ways of thinking were called by Aristotle *physikoi* or *physiologoi*, from their concern with *physis* or nature.

THE MILESIANS AND THE QUESTION OF ULTIMATE REALITY

These philosophical developments seem to have emerged first in Ionia on the west coast of Asia Minor (present-day Turkey, just across the Aegean Sea from the Greek mainland; see map 1). There Greek colonists had established thriving cities, such as Ephesus, Miletus, Pergamum, and Smyrna, whose prosperity was built on trade and the exploitation of local natural resources. Ionia may, like many frontier societies, have encouraged hard work and self-sufficiency; in return, it offered prosperity and opportunity. It also brought Greeks into contact with the art, religion, and learning of the Near East, with which Ionia had cultural, commercial, diplomatic, and military contact. Important though these influences undoubtedly were, the critical factor was surely the availability of fully alphabetic writing and its wide dissemination among the Greek population. The result was a burst of creativity in lyric poetry and philosophy.

The earliest philosophers of whom we have any knowledge were from the city of Miletus on the coast of southern Ionia. The names Thales, Anaximander, and Anaximenes have come down to us from the sixth century, Leucippus from the fifth. The available fragments portray the earliest Milesian philosopher Thales as a geometer, astronomer, and engineer. He is alleged to have successfully predicted a solar eclipse in 585; however, the sources of the legend do not appear particularly reliable, and it is unlikely that Greek astronomical knowledge had reached the point in Thales' lifetime where such a prediction was possible. Other fragments assign him the theory that the earth (a flat disk) floats on water, a notion that may be a truer measure of his astronomical and cosmological sophistication.[7]

Our knowledge of all of the Milesians is plagued by the problem of questionable, fragmentary sources; and we must approach all claims about the early Greek philosophers with healthy skepticism. What seems undeniable, however, is their interest in the problem of the fundamental reality, the basic stuff of which the universe was made or out of which it emerged. Aristotle, writing in the fourth century B.C. (with his own axes to



Map 1. The Greek World about 450 B.C.

grind, and in possession of only fragmentary and indirect evidence himself), gave us the following account:

> For the original source of all existing things, that from which a thing first comes-into-being and into which it is finally destroyed, the substance persisting but changing in its qualities, this [the first philosophers] declare is the element and first principle of existing things, and for this reason they consider that there is no absolute coming-to-be or passing away, on the ground that such a nature is always preserved.[8]

Thales, according to Aristotle, considered water to be this most fundamental reality, though Aristotle could do no more than speculate on the reasoning that lay behind Thales' choice.

Other Milesians of the sixth century, presumably Thales' students or disciples (we have no exact knowledge of their lives), seem to have given different answers to the same question. Anaximander (fl. 550), according to a variety of late reports, believed the origin of things was to be found in the *apeiron,* the unlimited or boundless—"a huge, inexhaustible mass, stretching away endlessly in every direction," according to one of his modern interpreters.[9] From the *apeiron* emerged a seed, which gave rise to the cosmos. Finally, Anaximenes (fl. 545) appears to have argued that the underlying stuff was air, which can be rarefied or condensed to produce the variety of substances found in the world as we know it. It is worth noting that the Milesians were materialists and monists: that is, they judged the primary substance to be some kind of material stuff, and to be one.

All of this may seem primitive. And in one sense it is; it cannot be equated with, nor does it anticipate, any modern theory. But comparing the past with the present is a sure recipe for distorting the achievements of the past. When the Milesians are compared with their immediate predecessors, their importance becomes immediately apparent. In the first place, the Milesians asked a new sort of question: what is the origin of things, or what is the simple underlying reality that can take on a variety of forms to produce the diversity of substances that we perceive? This is a search for unity behind diversity and order behind change. Second, the answers offered by the Milesians contain none of the personification or deification of nature that we saw in Homer and Hesiod. The Milesians left the gods out. What they may have thought about the Olympian gods we do not (in most cases) know; but they did not invoke the gods to explain the origin and nature of things. Third, the Milesians seem to have been aware of the need not simply to state their theories, but also to defend them against critics or competitors. We thus see the beginnings of a tradition of critical assessment.[10]

Milesian speculations about the underlying stuff were only the beginning of a quest that has continued to our own day. In antiquity, the Milesians were succeeded by various schools of thought. Fifty years later Heraclitus (fl. 500) of Ephesus (an Ionian city not far from Miletus) associated the origin of things with fire: "this world-order did none of [the] gods or men make, but it always was and is and shall be: an everliving fire, kindling in measures and going out in measures."[11] In the second half of the fifth century, the materialism of the sixth century was adopted and ex-

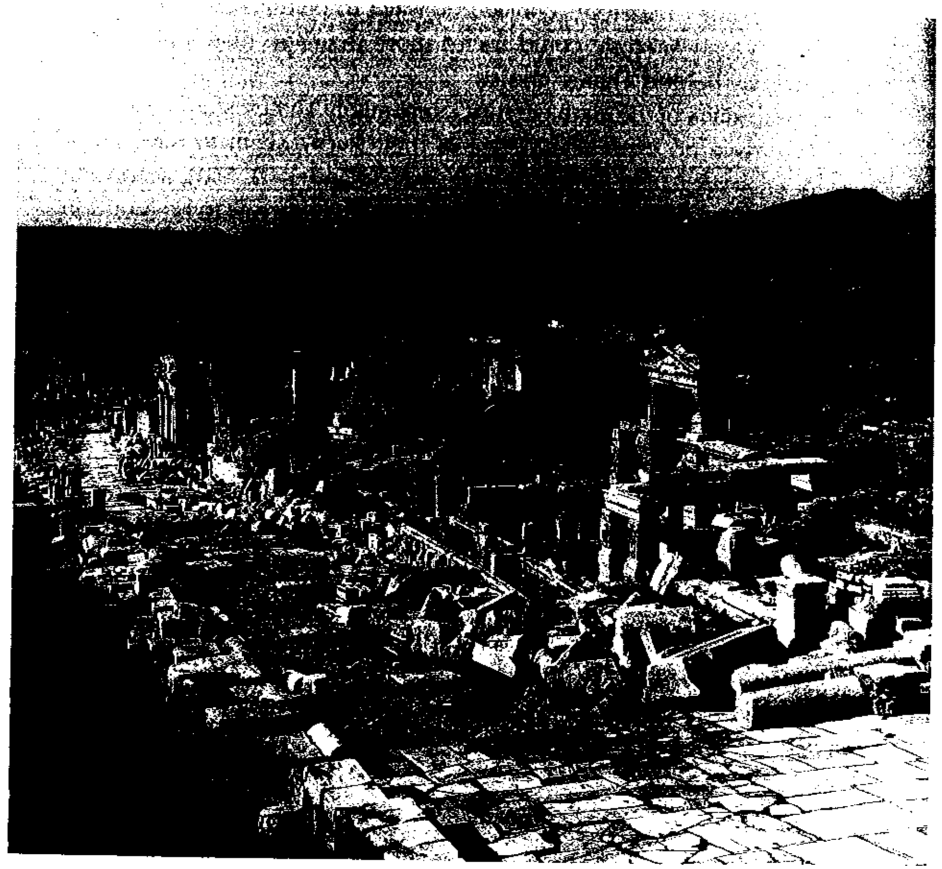


Fig. 2.3. The ruins of ancient Ephesus. SEF/Art Resource N.Y.

tended by the atomists Leucippus of Miletus (fl. 440) and Democritus of Abdera (fl. 410). Leucippus and Democritus argued that the world consisted of an infinity of tiny atoms moving randomly in an infinite void. The atoms, solid corpuscles too small to be seen, come in an infinitude of shapes; by their motions, collisions, and transient configurations, they account for the great diversity of substances and the complex phenomena that we experience. Leucippus and Democritus even attempted to explain the formation of worlds out of vortices or whirlpools of atoms.[12]

The atomists offered ingenious accounts of many other natural phenomena, but we must not allow ourselves to be diverted from the main point. What is important about the atomists is their vision of reality as a lifeless

piece of machinery, in which everything that occurs is the necessary outcome of inert, material atoms moving according to their nature. No mind and no divinity intrude into this world. Life itself is reduced to the motions of inert corpuscles. There is no room for purpose or freedom; iron necessity alone rules. This mechanistic worldview would fall out of favor with Plato and Aristotle and their followers; but it returned with a vengeance (and with a few novel twists) in the seventeenth century and has been a powerful force in scientific discussions ever since.

Not all who investigated the underlying stuff were monists or materialists. Nor were the gods altogether absent from their explanations. Empedocles of Acragas (fl. 450), a rough contemporary of Leucippus in the second half of the fifth century, identified four elements or "roots" (as he called them) of all material things: fire, air, earth, and water (introduced in mythological garb as Zeus, Hera, Aidoneus, and Nestis). From these four roots, Empedocles wrote, "sprang all things that were and are and shall be, trees and men and women, beasts and birds and water-bred fishes, and the long-lived gods too, most mighty in their prerogatives. For there are these things alone, and running through one another they assume many a shape."[13] But material ingredients alone cannot explain motion and change. Empedocles therefore introduced two additional, immaterial principles: love and strife, which induce the four roots to congregate and separate.

Empedocles was not the only ancient philosopher to include immaterial principles among the most fundamental things. The Pythagoreans of the sixth and fifth centuries (concentrated especially in the Greek colonies of southern Italy and known to us not as individuals but as a "school" of thought) seem to have argued, if we understand their doctrine, that the ultimate reality is numerical rather than material—not matter, but number. Aristotle reports that in the course of their mathematical studies the Pythagoreans were struck by the power of numbers to account for phenomena such as the musical scale. According to Aristotle, "since . . . all other things seemed in their whole nature to be modelled after numbers, and numbers seemed to be the first things in the whole of nature, they supposed the elements of numbers to be the elements of all things, and the whole heaven to be a musical scale and a number."[14] Now this is an obscure passage, and our uncertainty is compounded by the probability that Aristotle did not fully understand the Pythagorean teaching or was not altogether fair to it. Did the Pythagoreans literally believe that material things were constructed out of numbers? Or did they mean only to claim that material things have fundamental numerical properties and that such properties offer insight into the nature of things? We will never know for certain. A sensible reading of the Pythagorean position is that in some sense numbers come first, and everything else is their offspring; number is in that sense the fundamental reality, and material things derive their existence, or at least their properties, from number. If we wish to be more cautious, we can affirm at the very least that the Pythagoreans regarded number as a fundamental aspect of reality and mathematics as a basic tool for investigating this reality.[15]

THE PROBLEM OF CHANGE

If the most prominent philosophical problem of the sixth century was this question of the origins and fundamental ingredients of the world, a related issue came to dominate the philosophical enterprise in the fifth century. When we have truly discovered the fundamental ingredients of the world, can there be any doubt that we will find them to be unchangeable? It seems not: would something thought to be the ultimate reality be judged truly ultimate if it changed form or came into and passed out of existence? Would we not insist on explaining change in this entity by reference to something even more ultimate? At the end of the explanatory road, there must be something fixed and unchangeable. If we agree, then, that the ultimate reality must be unchangeable, is it possible to account for, or even to accept, the reality of change? Is stability at the level of ultimate reality compatible with genuine change on some other level? How can the world be both stable and changeable?

One of the earliest philosophers to address this question was Heraclitus, who offered a ringing declaration of the reality of change. Heraclitus is reputed to have claimed that nobody can step twice into the same river (because the second time it is no longer exactly the same river), and this aphorism made him the symbol, even in antiquity, of the opinion that everything is in a state of flux. Heraclitus also argued that a condition of overall equilibrium or stability may conceal underlying change in the form of counterbalancing forces or the struggle of opposites. For example, there is a perpetual struggle between the substances earth, water, and fire, each endeavoring to consume the others; however, dynamic equilibrium is achieved through overall balance or reciprocity.[16]

What Heraclitus affirmed Parmenides (fl. 480, from the Greek city-state at Elea in southern Italy) denied. Parmenides wrote a long philosophical poem (philosophy had not yet settled on prose as its exclusive form of discourse), large sections of which have survived. In it, Parmenides

adopted the radical position that change—all change—is a logical impossibility. Parmenides began by denying, on various logical grounds, the possibility that a thing should pass from non-being to being: for example, if a thing were to come into being, why at one moment rather than another, and by what means? His conclusion was that out of nothing comes nothing. "For never shall this be proved," he wrote, "that things that are not are."[17] Parmenides proceeded, on analogous grounds, to deny all other forms of change. He also denied the existence of time and plurality; what exists is one and now.

Parmenides' pupil Zeno (fl. 450) extended and defended the Parmenidean doctrine with a set of proofs against the possibility of one kind of change—motion, or change of place. One of these proofs, the "stadium paradox," will illustrate Zeno's approach. It is impossible, Zeno argued, ever to traverse a stadium, because before you cover the whole you must cover the half; and before you cover the half, you must cover the quarter; before the quarter, the eighth; and so on to infinity. To traverse a stadium is therefore to traverse an infinite sequence of halves, and it is impossible to traverse, or even "to come into contact with" (as Aristotle put it in his discussion of the paradox), an infinity of intervals in a finite time. The same argument may be applied to any spatial interval whatsoever—from which it follows that all motion is impossible.[18]

Now all of this may seem preposterous. With a little effort, Parmenides and Zeno could have opened their eyes and observed changes all around them. Did they not get up in the morning, enjoy a good breakfast, and make their way to the agora (the public square) for a hard day's philosophizing? And didn't they recognize that doing so required them to move? No doubt. Parmenides and Zeno knew perfectly well what experience taught, but the question was whether experience could be trusted. What does one do if experience suggests the reality of change, while careful argumentation (with due attention to the rules of logic) unambiguously teaches its impossibility? For Parmenides and Zeno, the answer was clear: the rational process must prevail. Parmenides distinguished between "the way of seeming," associated with observation, and "the way of truth," trod by reason. In his poem he warned against letting "custom, born of much experience, force thee to let wander along this road thy aimless eye, thy echoing ear or thy tongue; but do thou judge by reason the strife-encompassed proof that I have spoken."[19] So, yes, Parmenides and Zeno acknowledged that experience teaches the reality of change. But they knew on rational grounds that this was an illusion—a pleasant and powerful illusion, perhaps, but an illusion nonetheless.

Parmenides' denial of the possibility of change was enormously influential, offering a challenge that generations of philosophers felt compelled to address. Empedocles answered with his theory of four material "roots" or elements, plus love and strife. The elements do not come into being or pass away, and so the fundamental Parmenidean requirement is met; but they do congregate and separate and mix in various proportions, and thus change is genuine. The atomists Leucippus and Democritus granted that the individual atom is absolutely immutable, so that at the atomic level there is no generation, corruption, or alteration of any kind. However, the atoms are perpetually moving, colliding, and congregating; and through the motions and configurations of the atoms the endless variety in the world of sense experience is produced. According to the atomists, therefore, fundamental stability underlies superficial change; both are present, and both are real.[20]

THE PROBLEM OF KNOWLEDGE

Poking through these discussions of the underlying reality and the problem of change and stability has been a third basic issue, which early Greek philosophers also addressed—namely, the problem of knowledge (more technically known as epistemology). It is implicit in the quest for the fundamental reality underlying the variety of substances revealed by the senses: if the senses do not reveal the unity of things, then we must find other guides to the truth. The problem of knowledge is explicit in fifth-century discussions of change and stability. Parmenides' radical stance on the question of change had clear-cut epistemological implications: if the senses reveal change, their unreliability is thereby demonstrated; truth is to be gained only by the exercise of reason. The atomists, too, tended to denigrate sense experience. After all, the senses revealed the "secondary" qualities—colors, tastes, odors, and the tactile qualities—whereas reason taught that only atoms and the void truly exist. In a surviving fragment, Democritus identifies "two forms of knowledge, one genuine, one obscure. To the obscure belong all the following: sight, hearing, smell, taste, touch."[21] The fragment breaks off before the idea is completed, but we may assume that in Democritus's judgment genuine knowledge is rational knowledge.

If the early philosophers were inclined to favor reason over sense, this tendency was neither universal nor without qualification. Empedocles defended the senses against the attack of Parmenides. The senses may not be perfect, he argued, but they are useful guides if employed with discrimination. "But come, consider with all thy powers how each thing is manifest," he wrote, "neither holding sight in greater trust as compared with hearing, nor loud-sounding hearing above the clear evidence of thy tongue, nor withholding thy trust from any of the other limbs, wheresoever there is a path for understanding." And Anaxagoras (fl. 450) of Clazomenae (another Ionian coastal city) argued in a brief fragment that the senses offer "a glimpse of the obscure."[22]

One of the benefits gained from Greek epistemological concerns (from Greek rationalism in particular) was that they directed attention to the rules of reasoning, argumentation, and theory-assessment. Formal logic would be the creation of Aristotle; but his sixth- and fifth-century predecessors became increasingly aware of the need to test the soundness of an argument and to assess the grounds on which a theory rested. The sophistication with which Parmenides and Zeno could argue—their sensitivity, for example, to the rules of inference and the criteria of proof—demonstrates how far Greek philosophy had come in a century and a half.

PLATO'S WORLD OF FORMS

The death of Socrates in 399 B.C., coming as it did around the turn of the century (not on their calendar, of course, but on ours), has made it a convenient point of demarcation in the history of Greek philosophy. Thus Socrates' predecessors of the sixth and fifth centuries (the philosophers who have occupied us up to now in this chapter) are commonly called the "pre-Socratic philosophers." But Socrates' prominence is more than an accident of the calendar, for Socrates represents a shift in emphasis within Greek philosophy, away from the cosmological concerns of the sixth and fifth centuries toward political and ethical matters. Nonetheless, the shift was not so dramatic as to preclude continuing attention to the major problems of pre-Socratic philosophy. We find both the new and the old in the work of Socrates' younger friend and disciple, Plato.

Plato (427-348/47) was born into a distinguished Athenian family, active in affairs of state; he was undoubtedly a close observer of the political events that led up to Socrates' execution. After Socrates' death, Plato left Athens and visited Italy and Sicily, where he seems to have come into contact with Pythagorean philosophers. In 388 Plato returned to Athens and founded a school of his own, the Academy, where young men could pursue advanced studies (see fig. 4.2). Plato's literary output appears to have consisted almost entirely of dialogues, the majority of which have survived. We will find it necessary to be highly selective in our examination of Plato's philosophy; let us begin with his quest for the underlying reality.[23]

In a passage in one of his dialogues, the *Republic,* Plato reflected on the

Fig. 2.4. Plato (1st century A.D. copy), Museo Vaticano, Vatican City. Alinari/Art Resource N.Y.

relationship between the actual tables constructed by a carpenter and the idea or definition of a table in the carpenter's mind. The carpenter replicates the mental idea as closely as possible in each table he makes, but always imperfectly. No two manufactured tables are alike down to the smallest detail, and limitations in the material (a knot here, a warped board there) insure that none will fully measure up to the ideal.

Now, Plato argued, there is a divine craftsman who bears the same relationship to the cosmos as the carpenter bears to his tables. The divine craftsman (the Demiurge) constructed the cosmos according to an idea or plan, so that the cosmos and everything in it are replicas (and always imperfect ones because of limitations inherent in the materials) of eternal ideas or forms. In short, there are two realms: a realm of forms or ideas, containing the perfect idea of every single thing; and the material realm in which these forms or ideas are imperfectly replicated.

Plato's notion of two distinct realms will seem strange to many people, and we must therefore stress several points of importance. The forms are incorporeal, intangible, and insensible; they have always existed, sharing the property of eternality with the Demiurge; and they are absolutely changeless. They include the form, the perfect idea, of everything in the material world. One does not speak of their location, since they are incorporeal and therefore not spatial. Although incorporeal and imperceptible by the senses, they objectively exist; indeed, true reality (reality in its fullness) is located only in the world of forms. The sensible, corporeal world, by contrast, is imperfect and transitory. It is less real in the sense that the corporeal object is a replica of, and therefore dependent for its existence upon, the form. Corporeal objects exist secondarily, while the forms exist primarily.

Plato illustrated this conception of reality in his famous "allegory of the cave," found in Book VII of the *Republic.* Men are imprisoned within a deep cave, chained so as to be incapable of moving their heads. Behind them is a wall, and beyond that a fire. People walk back and forth beneath the wall, holding above it various objects, including statues of humans and animals, which cast shadows on the wall of the cave visible to the prisoners. The prisoners see only the shadows cast by these statues and other objects; and, having lived in the cave from childhood, they no longer recall any other reality. They do not suspect that these shadows are but imperfect images of objects that they cannot see; and consequently they mistake the shadows for the real.

So it is with all of us, says Plato. We are souls imprisoned in bodies. The shadows of the allegory represent the world of sense experience. The soul, peering out from its prison, is able to perceive only these flickering shadows, and the ignorant claim that this is all there is to reality. However, there do exist the statues and other objects of which the shadows are feeble representations and also the humans and animals of which the statues are imperfect replicas. To gain access to these higher realities, we must escape the bondage of sense experience and climb out of the cave until we find ourselves able, finally, to gaze on the eternal realities, thereby entering the realm of true knowledge.[24]

What are the implications of these views for the concerns of the pre-Socratic philosophers? First, Plato equated his forms with the underlying reality, while assigning derivative or secondary existence to the corporeal world of sensible things. Second, Plato has made room for both change and stability by assigning each to a different level of reality: the corporeal realm is the scene of imperfection and change, while the realm of forms is characterized by eternal, changeless perfection. Both change and stability are therefore genuine; each characterizes something; but stability belongs to the forms and thus shares their fuller reality.

Third, as we have seen, Plato addressed epistemological issues, placing observation and true knowledge (or understanding) in opposition. Far from leading upward to knowledge or understanding, the senses are chains that tie us down; the route to knowledge is through philosophical reflection. This is explicit in the *Phaedo,* where Plato maintains the uselessness of the senses for the acquisition of truth and points out that when the soul attempts to employ them it is inevitably deceived.

Now the short account of Plato's epistemology frequently ends here; but there are important qualifications that it would be a serious mistake to omit. Plato did not, in fact, dismiss the senses altogether, as Parmenides had done and as the passage from the *Phaedo* might suggest Plato did. Sense experience, in Plato's view, served various useful functions. First, sense experience may provide wholesome recreation. Second, observation of certain sensible objects (especially those with geometrical aspects) may serve to direct the soul toward nobler objects in the realm of forms; Plato used this argument as justification for the pursuit of astronomy. Third, Plato argued (in his theory of reminiscence) that sense experience may actually stir the memory and remind the soul of forms that it knew in a prior existence, thus stimulating a process of reflection that will lead to actual knowledge of the forms. Finally, although Plato firmly believed that knowledge of the eternal forms (the highest, and perhaps the only true, form of knowledge) is obtainable only through the exercise of reason, the changeable realm of matter is also an acceptable object of study. Such studies serve the purpose of supplying examples of the operation of reason in the cosmos. If this is what interests us (as it sometimes did Plato), the best method of exploring it is surely through observation. The legitimacy and utility of sense experience are clearly implied in the *Republic,* where Plato acknowledged that a prisoner emerging from the cave first employs his sense of sight to apprehend living creatures, the stars, and finally the most noble of visible (material) things, the sun. If he aspires to apprehend "the essential reality," then he must proceed "through the discourse of reason unaided by any of the senses." Both reason and sense are thus instruments worth having; which one we employ on a particular occasion will depend on the object of study.[25]

There is another way of expressing all of this, which may shed light on Plato's achievement. When Plato assigned reality to the forms, he was, in fact, identifying reality with the properties that classes of things have in common. The bearer of true reality is not (for example) this dog with the droopy left ear or that one with the menacing bark, but the idealized form of a dog shared (imperfectly, to be sure) by every individual dog—that by virtue of which we are able to classify all of them as dogs. Therefore, to gain true knowledge, we must set aside all characteristics peculiar to things as individuals and seek the shared characteristics that define them into classes. Now stated in this modest fashion, Plato's view has a distinctly modern ring: idealization is a prominent feature of a great deal of modern science; we develop models or laws that overlook the incidental in favor of the essential. (Galileo's inertial principle, for example, was an attempt to describe motion under ideal circumstances, all resistance or interference being excluded.) However, Plato went beyond this, maintaining not merely that true reality is to be found in the common properties of classes of things, but also that this common property (the idea or form) has objective, independent, and indeed prior existence.

PLATO'S COSMOLOGY

The doctrines that we have been considering—Plato's response to the pre-Socratics, found in his *Republic, Phaedo,* and various other dialogues—represent only a small portion of his total philosophy. Plato also wrote a dialogue, the *Timaeus,* which reveals his interest in the world of nature. Here we find his views on astronomy, cosmology, light and color, the elements, and human physiology. Since the *Timaeus* gave the early Middle Ages (before the twelfth century) its only coherent natural philosophy, this work represents one of the principal channels of Platonic influence and therefore demands our attention.

Plato referred to the contents of the *Timaeus* as a "likely story," and this has misled some readers to view it as a myth in which Plato himself placed no stock. In fact, Plato stated quite clearly that this was the best account possible, that anything better than a likely account was precluded by the subject matter. Certainty is attainable only when we give an account of the eternal and unchanging forms; when we describe the imperfect and changeable, our description will inevitably share in the imperfection and changeability of its subject—and will therefore be no better than "likely."

What do we find in the *Timaeus?* One of its most striking characteristics is Plato's vehement opposition to certain features of pre-Socratic thought. The *physikoi* had deprived the world of divinity; in the process, they had also deprived it of plan and purpose. According to these philosophers, things behave according to their inherent natures, and this alone accounts for the order and regularity of the cosmos. Order, then, is intrinsic, rather than extrinsic; it is not imposed by an outside agent but arises from within.

Now Plato found such an opinion not only foolish but dangerous. He had no intention of restoring the gods of Mount Olympus, who interfered in the day-to-day operation of the universe, but he was convinced that the order and rationality of the cosmos could only be explained as the imposition of an outside mind. If the *physikoi* found the source of order in *physis* (nature), he would locate it in *psychē* (mind).[26]

Plato depicted the cosmos as the handiwork of a divine craftsman, the Demiurge. The Demiurge, according to Plato, is a benevolent craftsman, a rational god (indeed, the very personification of reason), who struggles against the limitations inherent in the materials with which he must work in order to produce a cosmos as good, beautiful, and intellectually satisfying as possible. The Demiurge takes a primitive chaos, filled with the unformed material out of which the cosmos will be constructed, and imposes order according to a rational plan. This is not creation from nothing, as in the Judeo-Christian account of creation, for the raw materials are already present and contain properties over which the Demiurge has no control; nor is the Demiurge omnipotent, for he is constrained and limited by the materials that he confronts. Nevertheless, Plato clearly intended to portray the Demiurge as a supernatural being, distinct from, and outside of, the cosmos that he constructed. Whether Plato meant his readers to take the Demiurge literally is another matter, much debated, and perhaps incapable of ever being resolved. What is not open to dispute is Plato's wish to declare that the cosmos is the product of reason and planning, that the order in the cosmos is rational order, imposed on recalcitrant materials from outside.

The Demiurge is not only a rational craftsman but also a mathematician, for he constructs the cosmos on geometrical principles. Plato took over the four roots or elements of Empedocles: earth, water, air, and fire. But under Pythagorean influence, he reduced them to something more fundamental—triangles. He thus formulated a "geometrical atomism." As two-dimensional figures, triangles are of course incorporeal; however, if suitably combined, they can be made into three-dimensional corpuscles, each different shape corresponding to one of the elements. It was already known in Plato's day that there are five, and only five, regular geometrical solids (symmetrical solid figures formed of plane surfaces, all identical); these are the tetrahedron (four equilateral triangles), the cube (six squares), the octahedron (eight equilateral triangles), the dodecahedron (twelve pentagons), and the icosahedron (twenty equilateral triangles). (See fig. 2.5.) Plato associated each of the elements with one of these figures—fire with the tetrahedron (the smallest, sharpest, and most mobile of the regular solids), air with the octahedron, water with the icosahedron, and earth with the most stable of the regular solids, the cube. Finally, Plato found a function for the dodecahedron (the regular solid closest to the sphere) by identifying it with the cosmos as a whole.[27]

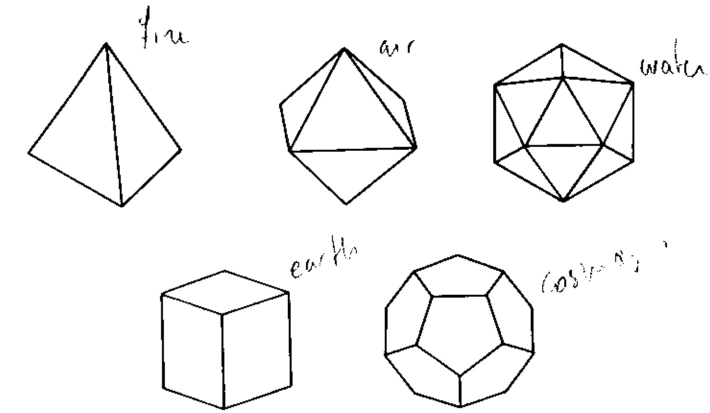


Fig. 2.5. The five Platonic solids: tetrahedron, octahedron, icosahedron, cube, and dodecahedron. Courtesy of J. V. Field.

Three features of this scheme deserve discussion. First, it accounts for change and diversity in the same way as does Empedocles' theory: the elements can mix in various proportions to produce variety in the material world. Second, it allows for transmutation of the elements from one to another, thus further accounting for change. For example, a single corpuscle of water (the icosahedron) can be dissolved into its twenty constituent equilateral triangles, which can then recombine into, say, two corpuscles of air (the octahedron) and one of fire (the tetrahedron). Only earth, which is composed of squares (and the square divided diagonally does not yield equilateral triangles), is excluded from this process of transmutation. Third, Plato's geometrical corpuscles represent a significant step toward the mathematization of nature. Indeed, it is important for us to see just how large a step it is. Plato's elements are not material substance packaged as the regular solids; in such a scheme matter would still be acknowledged as the fundamental stuff. For Plato, the shape is all there is; corpuscles are entirely reducible (without residue) to the regular solids, which are reducible to plane geometrical figures. Water, air, and fire are not *triangular;* they are simply *triangles.* The Pythagorean program of reducing everything to mathematical first principles has been fulfilled.

Plato proceeded to describe many features of the cosmos; let us glance at a few of them. He demonstrated a rather sophisticated command of cosmology and astronomy. He proposed a spherical earth, surrounded by the spherical envelope of the heavens. He defined various circles on the celestial sphere, marking the paths of the sun, moon, and other planets. He understood that the sun moves around the celestial sphere once a year on a circle (which we call the ecliptic) tilted in relation to the celestial equator (see fig. 2.6). He knew that the moon makes a monthly circuit of approximately the same path. He knew that Mercury, Venus, Mars, Jupiter, and Saturn do the same, each at its own pace and with occasional reversals, and that Mercury and Venus never stray far from the sun. He even knew that the overall motion of the planetary bodies (if we combine their slow motion around the ecliptic with the daily rotation of the celestial sphere) is spiral. And what is perhaps most important of all, Plato seems to have understood that the irregularities of planetary motion can be explained by the compounding of uniform circular motions.[28]

When Plato descended from the cosmos to the human frame he offered an account of respiration, digestion, emotion, and sensation. He had a theory of sight, for example, which supposed that visual fire issues from the eye, interacting with external light to create a visual pathway that could transmit motions from the visible object to the observer's soul. The *Timaeus* even offered a theory of disease and outlined a regimen that was to insure health.

It is an admirable cosmos that Plato has portrayed. What are its most prominent features? From triangles and regular solids the Demiurge fashioned a final product of the utmost rationality and beauty; and that means, according to Plato, that the cosmos must be a living creature. The Demiurge, we read in the *Timaeus,* "wishing to make the world most nearly like that intelligible thing which is best and in every way complete, fashioned it as a single visible living creature." But if the world is a living creature, it must possess a soul. And indeed it does; in the center of the cosmos the Demiurge "set a soul and caused it to extend throughout the whole and further wrapped its body round with soul on the outside; and so he established one world alone, round and revolving in a circle, solitary but able by reason of its excellence to bear itself company, needing no other acquaintance or friend but sufficient to itself." The world soul is ultimately responsible for all motions in the cosmos, just as the human soul is responsible for the motions of the human body. We see here the origins of the strong animistic strain that was to remain an important feature of the Platonic tradition. Repelled by the lifeless necessity of the atomistic world, Plato has described an animated cosmos, permeated by rationality, replete with purpose and design.[29]

Nor is deity absent. There is the Demiurge, of course; but in addition Plato assigned divinity to the world soul and considered the planets and the fixed stars to be a host of celestial gods. However, unlike the gods of traditional Greek religion, Plato's deities never interrupt the course of na-

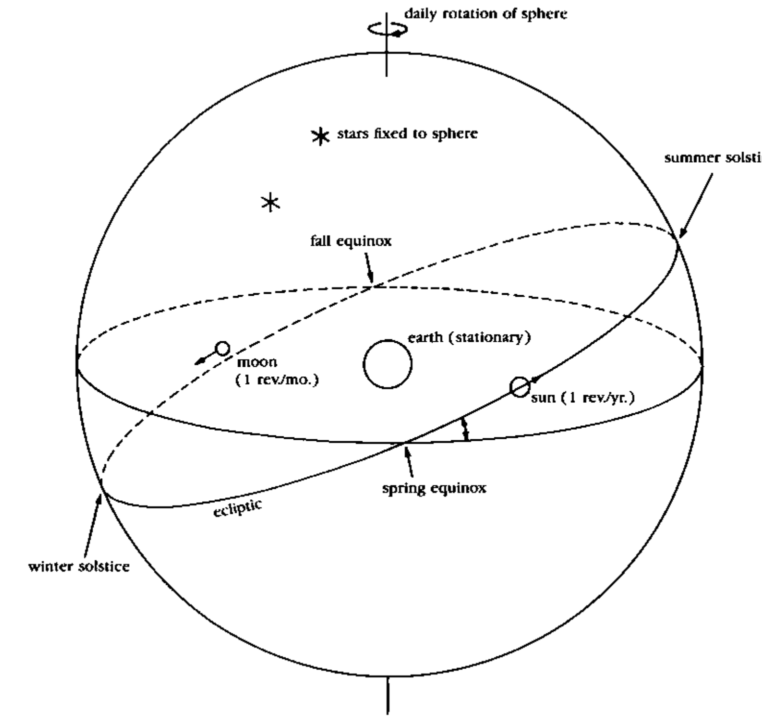


Fig. 2.6. The celestial sphere according to Plato.

ture. Quite the contrary, it is the very steadfastness of the gods which, in Plato's view, guarantees the regularity of nature; the sun, moon, and other planets *must* move with some combination of uniform circular motions precisely because such motion is most perfect and rational, and consequently such motion is the only kind conceivable for a divine being. Thus Plato's reintroduction of divinity does not represent a return to the unpredictability of the Homeric world. Quite the contrary, the function of divinity for Plato was to undergird and account for the order and rationality of the cosmos. Plato restored the gods in order to account for precisely those features of the cosmos which, in the view of the *physikoi,* required the banishing of the gods.[30]

THE ACHIEVEMENT OF EARLY GREEK PHILOSOPHY

If we survey early Greek philosophy with a modern scientific eye, certain pieces of it look familiar. The pre-Socratic inquiry into the shape and arrangement of the cosmos, its origin, or its fundamental ingredients reminds us of questions still investigated in modern astrophysics, cosmology, and particle physics. However, other pieces of early philosophy look considerably more foreign. Working scientists today do not inquire whether change is logically possible or where true reality is to be found; and it would be a considerable feat to turn up, say, a physicist or chemist who worries about how to balance the respective claims of reason and observation. These matters are no longer talked about by scientists. Does it follow that the early philosophers who devoted their lives to such questions were "unscientific," perhaps even misguided or dim-witted?

This question needs to be handled with some delicacy. Surely the fact that the *physikoi* were concerned about some matters no longer of interest is no indictment of their enterprise; in the course of any intellectual endeavor some problems get resolved, while others go out of fashion. But the objection may go deeper than that: are there issues that are intrinsically inappropriate or illegitimate, questions that were futile from the beginning? And did Plato and the *physikoi* waste their time on any of these? Perhaps we can answer in this way. Themes such as the identity of the ultimate reality, the distinction between natural and supernatural, the source of order in the universe, the nature of change, and the foundations of knowledge are quite different from the explanation of small-scale observational data (say, the descent of a heavy body, a chemical reaction, or a physiological process) that have occupied scientists for the past few centuries; but to be different is not to be insignificant. At least until Isaac Newton, these larger themes demanded as much attention from the student of nature as did the problems that now fill up a university course in science. Such questions were interesting and essential precisely because they were part of the effort to create a conceptual framework and a vocabulary for investigating the world. They were foundational questions; and it is often the fate of foundational questions to seem pointless to later generations who take the foundations for granted. Today, for example, we may find the distinction between the natural and supernatural obvious; but until the distinction was carefully drawn, the investigation of nature could not properly begin.

Thus the early philosophers began at the only possible place: the beginning. They created a conception of nature that has served as the foundation of scientific belief and investigation in the intervening centuries—the conception of nature presupposed, more or less, by modern science. In the meantime many of the questions they asked have been resolved—often with rough-and-ready solutions, rather than definitive ones, but resolved sufficiently to slip from the forefront of scientific attention. As they have sunk from view, their place has been taken by a collection of much narrower investigations. If we would understand the scientific enterprise in all of its richness and complexity, we must see that its two parts—the foundation and the superstructure—are complementary and reciprocal. Modern laboratory investigation occurs within a broad conceptual framework and cannot even begin without expectations about nature or the underlying reality; in turn, the conclusions of laboratory research reflect back on these most fundamental notions, forcing refinement and (occasionally) revision. The historian's task is to appreciate the enterprise in all of its diversity. If the garden of the *physikoi* is situated at the beginning of the road to modern science, then the historian of science may profitably dally in its shady corners before embarking on his journey.