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Understanding Nature—Form and Function

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INTRODUCTION

The goal of the *Science as a Way of Knowing* project is to offer background materials to those who teach the introductory biology courses in the colleges and universities. Since these courses tend to be the ones most heavily elected by students and, apart from science majors, may be the only science taken in college, the teachers of these courses have a heavy responsibility. They must prepare the non-science students to function adequately in a world dominated by science and technology and to make those informed decisions demanded of responsible citizens. And beyond preparing these responsible citizens, there is a great need to improve the biological education of students anticipating a career of teaching in the precollege grades.

In addition to these societal requirements for individuals with an understanding of science, there is a personal one. The alienation from the modern world that so many people feel might be lessened if science could be presented in a manner that captures their minds and hearts. Properly taught, science can become the most liberating of the Liberal Arts.

We suggest that an effective way of presenting first-year biology involves an emphasis on the conceptual framework of the discipline, a ruthless de-emphasis of the incredible terminology that plagues many introductory courses and texts, an explicit concern with important human problems for which the biological sciences may suggest solutions, and an emphasis on the strengths and limitations of scientific procedures.

The reform of biology teaching is but part of the overall reform in American education that has now become a national priority. Education is largely a codification of the *status quo* and the current pattern was set when life moved slowly, resources were "unlimited," and the poverty of other nations and of some citizens of our own was not prominent in our consciousness. Today there is a rapidly growing need to use our available knowledge to deal with the problems and prospects of the human experiment. An important component of that knowledge will be what has been learned in the sciences, of which biology is of more than average importance.

Since *Science as a Way of Knowing* is now in its fifth year, it is not necessary to discuss the rationale for the project yet another time. Previous discussions are to be found in the already published proceedings: *Science as a Way of Knowing* (1984, pp. 421–422, 469–476; 1985, pp. 377–378, 486–489, 612–615; 1986, pp. 573–581, 586–589; 1987, 417–421).

Cross references to the earlier publications in this series will be given as "SAAWOK–II, pp. —" etc.

It must be remembered that these Essays provide *background* materials and, as such, their emphasis differs greatly from that of introductory textbooks of biology. You will find far more details than can or should be included in first-year biology courses. These details are intended to help provide the basis of a conceptual framework of biology. The concern is the development of ideas, not to present a balanced history, so the emphasis will be on key individuals and key concepts. Put another way, this Essay will be concerned with basic questions and basic answers. To the degree that both show a sequence in time, what is written will reflect historical events.

There will also be an emphasis on a few individuals, who will be taken to represent the questions and answers for a given time. For example Robert Hooke is cited, not only for his discovery of cells, but also for what he had to say about fossils. Although his analysis of fossils was outstanding, it was not unique. Some of his peers could have been cited in his stead. My emphasis on

Hooke is deliberate and it has to do more with how we teach than how we report historical events. Students will "know" Hooke when, after their previous encounter with him in relation to cells, they come to his work on fossils. This may help to impress upon them that science is done by individual human beings and not by "they." Ideally the students will conclude that "Robert Hooke and other 17th century naturalists proposed that fossils have an organic origin" rather than "In the 17th century they proposed that fossils have an organic origin."

This Essay will recount the ways, from prehistory to the present, that human beings have attempted to "explain" the living world and to understand their relation with it. The Animal Kingdom will be emphasized.

The Retreat From Nature in the Modern World

It is not surprising that *Homo sapiens,* nature's dominant heterotroph, has had an ongoing interest in the animals and plants of his environment. It cannot be otherwise. To be sure the level of interest was and continues to be higher in those individuals of our species who secure their food directly from the environment. Once upon a time nearly all human beings were so occupied but, beginning with settled villages and later cities (about 5,000 years ago), the percentage of those securing their own food directly from farming slowly decreased.

This decrease was gradual even in the technologically advanced nations. The first census of the United States, in 1790, counted 202,000 urban individuals compared with 3,728,000, or 95 percent, living in rural areas (*United States Bureau of the Census,* 1975, Series A 34-50). In 1910 the rural population was still slightly greater, 54 percent of the total, than the urban. More recent statistics divide the rural population into farm and nonfarm. By 1960 the farm population had dropped to 5.1 percent and most recently to 2.2 percent, of the total population (*United States Bureau of the Census,* 1987, Table 1093).

Thus, over the long eons of human history, our species has had a close contact with living organisms and especially with those used for food. The historically recent breaking of that direct contact has had enormous consequences—life takes on new directions and new meaning when human beings no longer have the possibility of obtaining their food directly. When that happens, one of their most basic requirements for life is at risk.

The manner in which human beings attempt to understand living creatures depends upon how they answer the question "What is the real world?" Historically there have been two answers, essentially incompatible. One is that the real world is that of matter, energy, and obvious things; the other answer is that the real world resides beyond the obvious.

> The men who ask these questions as to the ultimate reality of the world are philosophers in the widest sense of the word, and, roughly speaking, their answers fall into one of two classes according as they find the ultimate reality of the world in matter or in mind. On the one view, the ultimate reality is dead, unconscious, inhuman; on the other view, it is living, conscious, and more or less analogous to human feeling and intelligence; according to the one, things existed first and mind was developed out of them afterwards; according to the other, mind existed first and created, or at all events set in order, the realm of things. On the one view, the world is essentially material; on the other, it is essentially spiritual. Broadly speaking, science accepts the former view, at least as a working hypothesis; religion unhesitatingly embraces the latter. Whichever hypothesis be adopted, the mind, in obedience to a fundamental law, seeks to form a conception which will simplify, and if possible unify, the multitudinous and seemingly heterogeneous phenomena of nature (J. Frazer, 1926, p. 3).

These are fundamental and fascinating questions and to this day they are answered differently by different minds—and differently by the same mind at different times or when dealing with diverse phenomena.

Unfortunately we cannot know how prehistoric human beings answered these questions. We can do no more than speculate on the basis of the surviving artifacts and on what the anthropologists tell us about the beliefs of the peoples they study. Nevertheless the various sources of information do suggest some general conclusions, namely, that there was a point of view that unites the real world of the scientist with the world of hope, imagination, emotion, religion, and the supernatural.

ANIMISM

This conclusion is based on the fact that, among the preliterate societies studied during the past two centuries by anthropologists, similar patterns of belief are found worldwide: for each "thing" in the natural world of our senses, there is a supernatural force—spirit, soul, specific energy, life—that accounts for the nature and behavior of the "thing." In its most general form this belief postulated a specific soul in every rock, mountain top, animal, plant, spring, breeze.

This system of belief is known as animism. The term is derived, not from "animal," but from a root common to both—the Latin *anima* meaning soul or life. Animism sees a duality in the phenomena of nature: there is the phenomenon and the spirit of the phenomenon. Animism avoids the problem of seeking natural *or* supernatural explanations as described before in the quotation from Sir James Frazer. Spirit and substance are aspects of the same thing.

> Savages explain the phenomena of nature and of human life by supposing the existence of a multitude of spiritual beings, whether gods or ghosts, who people the sky, the air, the sea, the woods, the springs, the rivers, and by their actions bring about all the varied effects which a materialistic philosophy refers to the agency of impersonal forces (J. Frazer, 1926, p. 5).

The earliest animistic beliefs probably held that every natural object had its own spirit. That seems necessary to account for the variation that does occur among similar things. Thus, there was a specific spirit for one spring and a different spirit for another. Later it was believed that there were generalized spirits—one for all springs, for example.

Thus, a rabbit, or a tree, or a spring owed its specific nature to a rabbit-spirit, tree-spirit, or a spring-spirit. A rabbit behaves like a rabbit because it has a rabbit-spirit. This pattern of thought, which says no more than a rabbit behaves like a rabbit because it is a rabbit, does seem to lack a certain logical economy. Nevertheless this ancient mode of explanation is accepted by many people today as a satisfying way to understand the phenomena of nature.

This way of looking at the world prevailed on all continents and it is important to ask why. One hypothesis could be that these ideas arose in one place and slowly spread throughout the world over many millennia. This hypothesis requires that the basic ideas remain more or less the same for all preliterate races and "make sense" to all.

A more likely hypothesis, I believe, is that a generalized animism is a reasonable way for preliterate people to deal with such otherwise inexplicable phenomena as death, dreams, sleep, apparitions, illness, unconsciousness—and even aspects of thought itself. This is the analysis of Edward B. Tylor who is considered to be one of the founding fathers of anthropology (the other is Sir James Frazer, quoted before).

> The idea of the soul which is held by uncultured races, and is the foundation of their religion, is not difficult to us to understand, if we can fancy ourselves in their place, ignorant of the very rudiments of science, and trying to get at the meaning of life by what the senses seem to tell. The great question that forces itself on their minds is one that we with all our knowledge cannot half answer, what the life is which is sometimes in us, but not always. A person who a few minutes ago was walking and talking, with all his senses active, goes off motionless and unconscious in a deep sleep, to awake after a while with renewed vigor. In other conditions the life ceases more entirely, when one is stunned or falls into a swoon

> or trance, where the beating of the heart and breathing seem to stop, and the body, lying deadly pale and insensible, cannot be awakened; this may last for minutes or hours, or even days, and yet after all the patient revives. Barbarians are apt to say that such a one died for a while, but his soul came back again. They have great difficulty in distinguishing real death from such trances. They will talk to a corpse, try to rouse it and even feed it, and only when it becomes noisome and must be got rid of from among the living, they are at last certain that the life has gone never to return. What, then, is this soul or life which thus goes and comes in sleep, trance, and death? To the rude philosopher, the question seems to be answered by the very evidence of his senses. When the sleeper awakens from a dream, he believes he has really somehow been away, or that other people have come to him. As it is well known by experience that men's bodies do not go on these excursions, the natural explanation is that every man's living self or soul is his phantom or image, which can go out of his body and see and be seen itself in dreams. Even waking men in broad daylight sometimes see these human phantoms, in what are called visions or hallucinations. They are further led to believe that the soul does not die with the body, but lives on after quitting it, for although a man may be dead and buried, his phantom-figure continues to appear to the survivors in dreams and visions .... Here then in few words is the savage and barbaric theory of souls, where life, mind, breath, shadow, reflexion, dream, vision, come together and account for one another in some such vague confused way as satisfies the untaught reasoner ....
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> It may have occurred to some readers that the savage philosopher ought, on precisely the same grounds, to believe his horse or dog to have a soul, a phantom-likeness of its body. This is in fact what the lower races always have thought and still think, and they follow the reasoning out in a way that surprises the modern mind, though it is quite consistent from the barbarian's point of view. If a human soul seen in a dream is a real object, then the spear and shield it carries and the mantle over its shoulders are real objects too, and all lifeless things must have their thin flitting shadow-souls (Tylor, 1881, pp. 342–343, 346).

Today's reader, who is less likely than the Victorians to think in terms of "savage" and "barbarian," may take pride in the fact that human beings at a preliterate stage of culture could develop such a consistent view of self and nature when both philosophy and science were disciplines of the future.

In fact we have in animism the beginnings of the way our remote ancestors sought to understand what for them could not be understood and to control that which could not be controlled. To them the world was dominated by unseen supernatural forces, the spirits or souls, that were part of all the phenomena of the world that could be seen, heard, and felt. The spirits were the true essences—they had a life of their own, perhaps an immortal one, that survived demise and decay.

Some thought that these liberated spirits could enter human beings and animals and, when they did, sickness and death was the consequence. By and large spirits were to be feared; calamities were their doing. In some instances they could be propitiated by offerings. This is how it appeared to Sir James Frazer:

> First, in regard to the worship of nature, I mean by that the worship of natural phenomena conceived as animated, conscious, and endowed with both the power and the will to benefit or injure mankind. Conceived as such they are naturally objects of human awe and fear. Their life and consciousness are supposed to be strictly analogous to those of men; and they are thought to be subject to the same passions and emotions, and to possess powers which, while they resemble those of man in kind, often far exceed them in degree. Thus to the mind of primitive man these natural phenomena

assume the character of formidable and dangerous spirits whose anger it is his wish to avoid, and whose favour it is in his interest to conciliate. To attain these desirable ends he resorts to the same means of conciliation which he employs towards human beings on whose good-will he happens to be dependent; he proffers requests to them, and he makes them presents; in other words, he prays and sacrifices to them; in short, he worships them. Thus what we may call the worship of nature is based on the personification of natural phenomena. Whether he acts deliberately in pursuance of a theory, or, as is more probable, instinctively in obedience to an impulse of his nature, primitive man at a certain stage, not necessarily the earliest, of his mental evolution attributes a personality akin to his own to all, or at all events to the most striking, of natural objects, whether animate or inaminate, by which he is surrounded. This process of personification appears to be the principal though it is probably not the only source of worship among simple folk (Frazer, 1926, pp. 17–18).

Most modern scholars of religion do not regard animism as a true religion but merely an early stage thereof. For one not steeped in theology, the distinction may not be entirely clear. Possibly it is an attempt by those who, by their own admission, have a "true" religion to distance themselves from those who do not. Nevertheless some of today's religions have vestiges of these ancient views, which probably date to Paleolithic times.

TOTEMISM

Animism is one dramatic way that human beings looked upon natural phenomena, including the Animal Kingdom. Totemism is another. Totemism is a social system in which there are clans and the members of the same clan have some living or nonliving object as their totem. Usually the totem is regarded as the ancestor from which all members of the clan are descended. The forebear of the bear clan was a bear. This is what that father of anthropology, Sir James Frazer (1934), had to say:

> A totem is a class of material objects which a savage regards with superstitious respect, believing that there exists between him and every member of the class an intimate and altogether special relation . . . . The connection between a man and his totem is mutually beneficent; the totem protects the man, and the man shows his respect for the totem in various ways, by not killing it if it be an animal, and not cutting or gathering it if it be a plant . . . . The clan totem is reverenced by a body of men and women who call themselves by the name of the totem, believing themselves to be of one blood, descendants of a common ancestor, and are bound together by common obligations to each other and by a common faith in totemism (Vol. 1, pp. 3–4).

Totemism was found among preliterate peoples throughout the world, being especially well-developed in North America and Australia. The name itself is derived from the language of the Ojibwa Indians of North America. The totems varied with the locality, some of those of the Indians of North America being: turtle, bear, wolf, crayfish, carp, dog, crane, buffalo, snail, beaver, eagle, pigeon, snake, coyote, turkey, and raven. It was not unusual for clan members to dress for ceremonies in such a way as to resemble the totem, the behavior of which could be imitated in dances.

Clans could have non-living totems as well: thunder, lightning, ice, water, floods, wind, rain, bone, or rainbow, for example.

Some clans believed that upon death the clan member reverted to his clan's ancestor—wolf, bear, or whatever.

Every tribe had at least two clans in the same locality as there was a strict prohibition of sexual relations or marriage among members of the same clan. The penalty for ignoring these prohibitions could be death.

When the clan's totem was an animal, which it generally was, obviously the clan members felt very close to that member of the Animal Kingdom. The totem animal was their remote ancestor, their protector in life, and possibly a form to return to after death.

SHAMANISM

This is still another belief system that invokes supernatural phenomena and suggests how very differently preliterate peoples of recent times and, by extension to prehistoric times, thought and believed. Shamanism was best developed in Siberia but elements occur throughout the world. The shaman ("he who knows") is a tribal medicine man who, through the ability to achieve ecstasy, can leave his body and undertake various assignments. In societies where shamanism is practiced it is believed that the shaman's skill is inherited.

The shaman's main role is to cure sickness, which results from a sick person's soul leaving his body. The shaman is able to pursue and capture the departed soul and return it to its rightful owner. However if all procedures fail and the patient dies, the shaman accompanies the soul on its long and difficult journey to the other world. As part of this ceremony the shaman, during his ecstasy, describes in graphic detail the events of the journey.

Because of the worldwide distribution of animism among preliterate people, as well as the fact that it was the dominant form of belief when historical records first became available, it is reasonable to assume that it had a long prehistory—possibly back to the time when human beings first sought to "explain." Less is known about totemism and shamanism but they too must have been very ancient. One can postulate that animism might be oldest since it saw an equivalence among all the objects of nature—each having substance as well as soul or spirit.

REFERENCES: THE PERSONIFICATION OF NATURE

This is a vast subject related as it is to religion, mythology, and how early human beings attempted to explain nature. The big questions still remain unanswered although earlier scholars, such as Sir James Frazer and Sir Edward Tylor, attempted to do so. Anthropologists today are less inclined to make the attempt whereas some students of religion do—Eliade (1978) for example.

The following references deal with animism, totemism, and how preliterate human beings attempted to understand the natural world. Here and throughout an * indicates a good place to start for those wishing more information or a reference of fundamental importance: Birket-Smith (1965), Boas (1916), Buchler and Maddock (1978), Budge (1934), Campbell (1970, vol. 1; *1983), Drucker (1965), Dupré (1975), *Durkheim (1915), Eliade (*1963, 1964, 1978, *1987), Elkin (1933–1934), *Encyclopedia Britannica (1985), Evans-Prichard (1965), Fairservis (1975), Ferreira (1965), Firth (1930–1931, 1960), *Frazer (1926, 1934, 1937), Freud (1918), Giedion (1962), Goldenweiser (1910, 1934), Gowlett (1984), Gray (1916–1932), Hastings (1951), Hawkes and Woolley (1963), Howey (1955), Hughes (1952), James (1963), Jensen (1963), Kirk (1970), Lévi-Strauss (1963, 1966), Lommel (1967), Lowie (1948), Malinowski (1948), Marett (1900, 1909), Maringer (1960), Monod (1971), Müller (1888), Piddington (1950), *Redfield (1953), *Tylor (1881, 1913), and Vignoli (1882).

THE PALEOLITHIC VIEW OF NATURE

Now we will switch to another sort of evidence, the artifacts, that can throw some light on how early human beings thought about nature.

The earliest evidence relating to animals consists of the broken bones associated with early human habitations, such as caves, or hearth sites (the use of fire dates to about 1.5 million years B.P. = "before present"). Seemingly the bones were broken deliberately, which suggests that the marrow was eaten. About all we learn from such data is that primitive human beings were hungry and liked marrow.

The earliest stone artifacts so far discovered date from about 2.5 million years B.P. (Gowlett, 1984). Various species of *Australopithecus* lived at that time and probably species of *Homo* as well. Other scholars place the earliest *Homo* species at about 2 million B.P. These dates are all from the end of the Tertiary Period—in the Pliocene Epoch.

About 1.6 million B.P. marked climatic changes began to occur in northern Europe and North America. Great ice sheets repeatedly advanced and retreated. This is the Pleistocene Epoch in geological terms, and the Old Stone Age, or Paleolithic Age, to the students of early human beings. The Paleolithic ended about 10,000 B.P.

During the interglacial periods, when much of the ice melted, climatic conditions in southern Europe were as mild as today and there is abundant evidence of the return of plant and animal life, including human beings to formerly glaciated regions. These interglacial periods might last as long as 10,000 years—presumably we are in one right now.

Homo sapiens sapiens, our subspecific version of humanity, dates from about 40,000 B.P. in the Near East and from about 30,000 B.P. in Europe—as Cro-Magnon people. This is now the Upper Paleolithic, as well as the closing millennia of the Pleistocene. The Cro-Magnon people were highly skilled in making tools from stone, bone, and presumably wood and other plant material (most of which would have decayed). They were hunters and gatherers. The discarded bones at their camp sites tell us of their vertebrate food—mainly horse and reindeer.

Representational art begins at this time—about 30,000 B.P. The many objects so far discovered can tell us something about what these early human beings thought about—and they thought a great deal about animals; those they ate and those that were huge and fierce, which presumably they feared.

The two principal sites that will be mentioned, the caves of Lascaux in France and of Altamira in Spain, are now generally thought to belong to the Magdalenian culture of the Late Paleolithic (Sandars, 1985). This was during the period of the Würm glaciation when western Europe was bitterly cold. Radiocarbon dates of 18,500 to 19,000 B.P. for near the beginning of the Magdalenian and of 10,740 B.P. near its end are available. A specific age for Altamira is 13,540 B.P. and Lascaux is thought to be about 2,000 years older.

The Dordogne region of southern France, east of Bordeaux, is a veritable museum of this Late Paleolithic art. Much of it has been discovered in caves where the chances of preservation would be far greater than in exposed areas.

One of the most famous sites is the Lascaux cave near the village of Montignac and on a plateau above the Vézère River. The story, possibly apocryphal, is that it was found in September 1940 by a dog that slipped into a hole. The youths accompanying the dog went into the hole to rescue the animal and found themselves in a large cave.

When local people and scientists first came to the cave to check the lads' story, they found that the main chamber was about 30 meters long, 10 meters wide, and 7 meters high. Other passages connected with the main cavern. Of greatest interest was the fact that the walls had been covered with more than a hundred paintings—in black, yellow, and red (Figs. 1–3). Superb color reproductions of the cave paintings were published subsequently and they are well worth examining (Windels, 1950; Bataille, 1955; Ruspoli, 1987). They convey something of the majesty and beauty of the cave itself.

The Lascaux cave was open to the public for a few years but the artificial light used to illuminate the cave, and moisture from the exhalations of thousands of tourists, caused a slimy growth that began to damage the paintings. The cave was then closed to the general public but a replica has been constructed nearby for visitors.

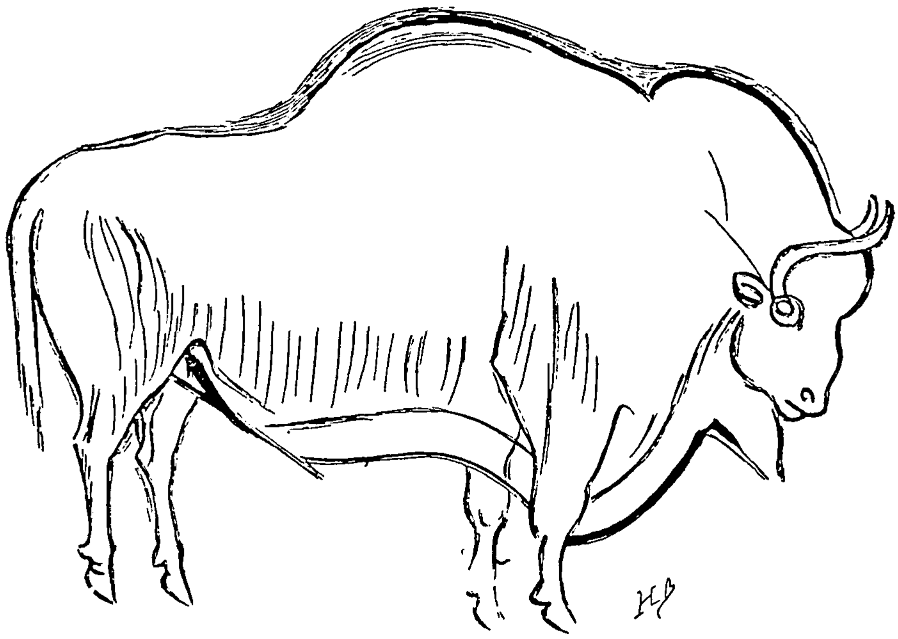
Since the cave is naturally totally dark, those Cro-Magnon artists would have needed to use some artificial light source. They certainly used lamps because some have been found in the cave. These were simple saucers in which fat was burned. Similar lamps were used as late as the early 20th century by the Eskimos and Aleuts of Alaska.

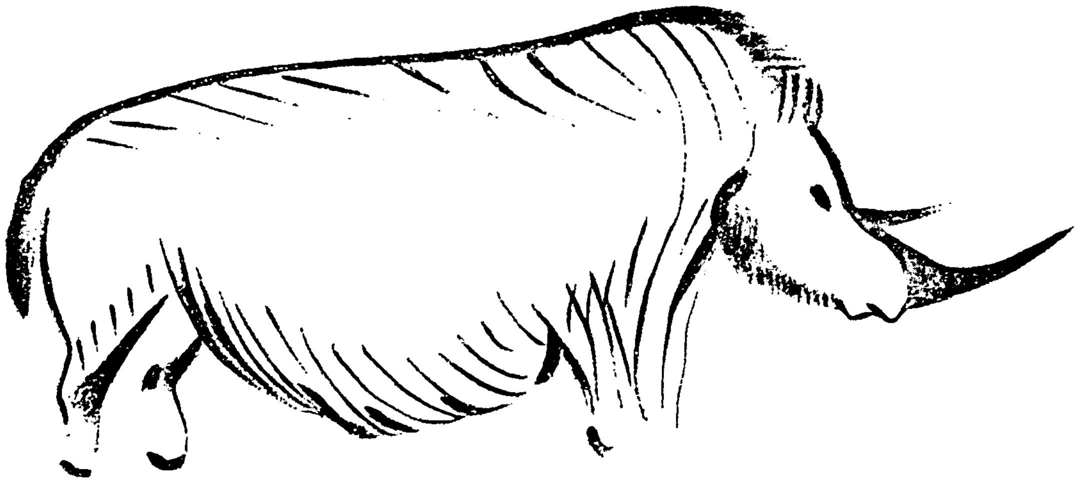
The paintings themselves have a primi-

FIG. 1. Paleolithic cave art. A stag is shown above. The upper figure on the facing page is of a bison and, below, a rhinoceros. Figures 1–3 are sketches made by the renowned historian of ancient man, the Abbé Henri Breuil (Breuil and Obermaier, 1935).

tive strength and economy of line and are of a genre that has great appeal to the modern eye. They can be characterized as "honest" in contrast, say, with the fluffiness of the French Baroque.

The fact that the painters of the Lascaux caves can be characterized as great artists—nearly two hundred centuries after they lived—points up an important difference between the humanities and the sciences. Great art is eternal; great science tends to be replaced by greater science. Cro-Magnon artists at the beginning of the visual arts, and Homer at the beginning of





Western literature, can hold their own with painters and writers of today. By way of contrast, the physics of today is far better physics than that of Issac Newton and our evolutionary biology is far better than that of Charles Darwin—in spite of the magnificent achievements of those notable Englishmen. Ezra Pound (1910) was not speaking for the sciences when he said, "All ages are contemporaneous."

We generally accept that the work of artists reveals the thoughts and passions of their times, so what was it that the Cro-Magnon artists of Lascaux painted? Ani-

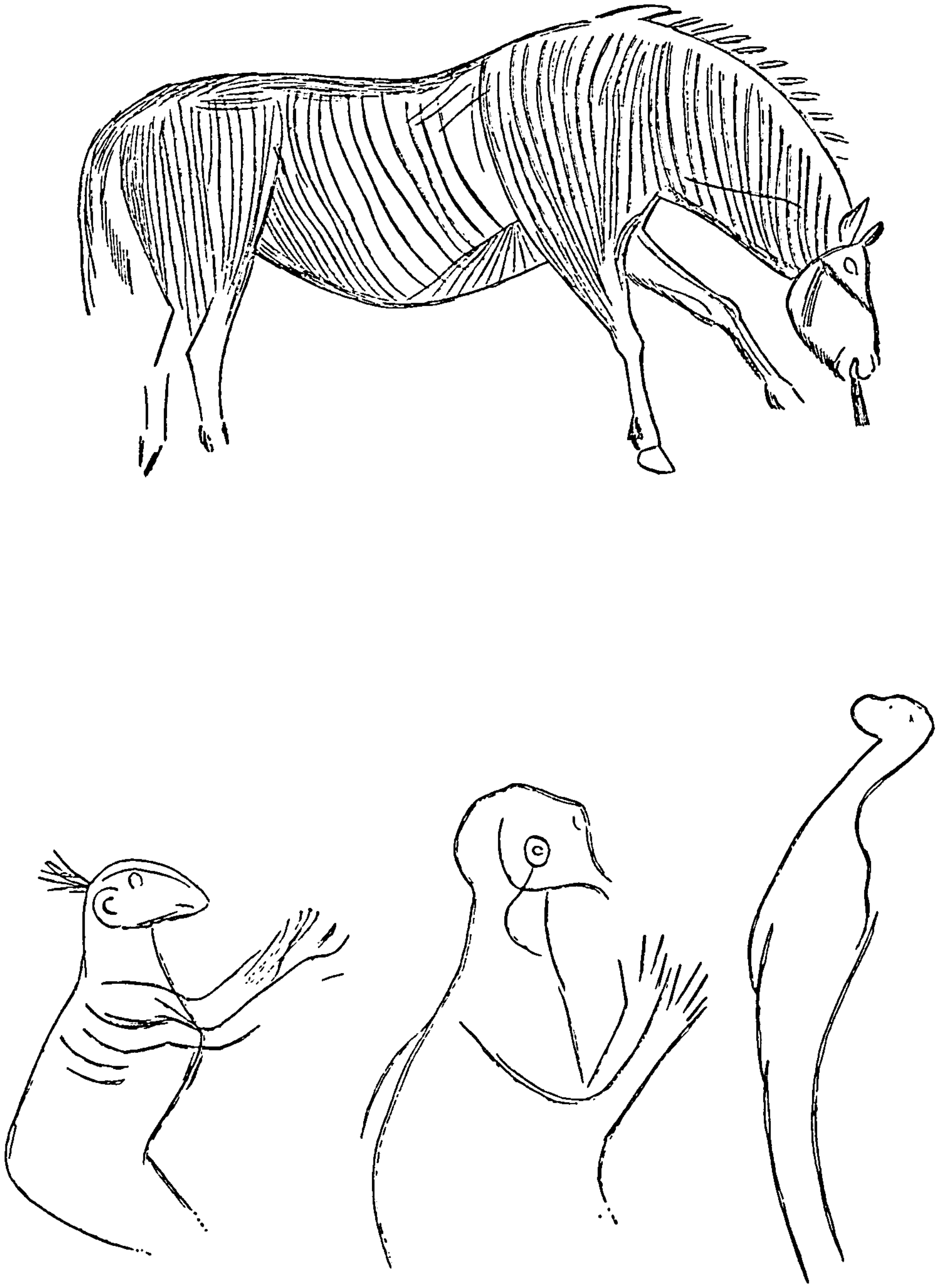


FIG. 2. Paleolithic cave art. Horse above and figures thought to be human beings below.

FIG. 3. Paleolithic cave art. Sketches of horses.

mals. There are more than a hundred paintings. The exact number is difficult to state because there has been some over-painting. The following estimates, however, are acceptably close to being correct.

Fifty percent wild horses. These were similar to the Przewalski horse, a few of which survive today in zoos. There are also representations of a few wild asses. Wild equids were common in Europe until shortly after the Middle Ages.

Sixteen percent wild oxen, or aurochs. These are *Bos primigenius.* The last wild ones in Europe are said to have been killed early in the 17th century.

Eleven percent deer, probably *Cervus elaphus,* which is still present in Europe.

Eleven percent ibex, *Capra ibex,* some of which still live in the Alps.

Five percent bison, which could have been either the Quaternary bison, *Bison priscus,* or the European bison, *Bison bonasus.* The bones cannot be readily distinguished. The last wild European bison were killed some time around World War I.

Two percent cave lions, *Felis leo.* These lasted in Western Europe until the end of the Pleistocene and are the same species as the lions in Asia and Africa today.

One percent each of bears (*Ursus arctos*), birds, rhinoceros (*Rhinoceros trichorhinus* or, more probably, *Rhinoceros merckii*), humans (*Homo sapiens sapiens*), and wolves.

There is also a creature, either imaginary or poorly drawn, that has been called a "unicorn." This is not a happy appellation since there appear to be *two* horns. For our purposes it will be referred to as a "duocorn" and listed as 1 percent. In addition, one of the drawings may be of a reindeer (*Rangifer tarandus*) and another of a musk ox (*Ovibos moschatus*). Both species are still living.

In addition to the paintings there are numerous engravings, which are not included in the data above but they show a similar distribution of subjects.

Many of the animals have been transfixed by spears, darts, or arrows. The one human being portrayed is either dead or dying. Towering over him is a huge bison, with a spear that has passed entirely through its body. The bison has been eviscerated and loops of the intestine are exposed. This wound might have been made by human hunters or by the rhinoceros that walks off to the left, defecating. Some scholars have interpreted this scene as the end of an unsuccessful hunt but Campbell (1970, p. 301) suggests that it is magical and that the person is a shaman.

The human figure is drawn in simple outline and has a bird-like beak and four fingers on each hand. The rendition is feeble compared with that of the other mammals. This is usual in Late Paleolithic art:

> What primeval man portrayed as his own image upon the walls of the caverns or upon carved bones appears barely human to our eyes. He is very far removed from the narcissism of a creature enamored of his own beauty, as the Greeks taught us to see ourselves. Primeval man depicts himself in no way as self-assured, self-reliant, and superior. Throughout prehistory man stands before us as a being oppressed by an eternal inferiority complex in the presence of the animal. He seems ashamed of the form given him by nature. He hides his face, he disregards his body (Giedion, 1962, p. 5).

There has been endless discussion of the "meaning" of these cave paintings. The fact that they are so excellent, and in a place so difficult for the painters to work, suggests that they must have some profound significance. They are not casual doodles. Are they no more than representations of the local fauna and food animals? Do they represent cult figures? Could it be that by portraying an animal transfixed by a spear, the hunter would be more successful? Does their location, deep in a dark cavern, suggest that they were involved in religious ceremonies? Or could it be that these large-brained hunters simply liked to paint? Here is one view:

> It is indeed around hunting that all the interests of Palaeolithic man are concentrated. The whole life of the tribe depends on the game which he brings home. The meat is used for food; the skins for clothing; needles and awls are made of the bones; the tendons serve for sewing; and also, no doubt, as bindings for the hafting of tools. Horns and antlers are of solid material, but easier to work than stone. The fat is used for lamps. On success in hunting the life of the group depends. But animals are swift and strong creatures; they know how to hide, and to fight. So man tries to conciliate the great unknown forces governing the world. Magic rites are enacted, in the mysterious depths of the caves, by sorcerers. Through their performances, tested by time and thence handed faithfully down the generations, the animals are held bound by magic forces; they will fall victims to every trap, and every dart will kill them. Magic force, too, will ensure the abundance of the game-supply, the reproduction of animals that do man good and the destruction of those that harm him. Around this explanation, even though it may seen at first a mere flight of fancy, most of the known facts can be brought together and made intelligible (Windels, 1950, pp. 53, 55).

In any event an incredible step toward civilization was taken by Paleolithic human beings at Lascaux and elsewhere. Imagine what an intellectual achievement it was to show that the objects of nature could be represented symbolically by a few lines. Think also of what this meant for communication and preservation of information. Here is an early stage of symbolic representation that went on to pictographs and then to an alphabet. There are nouns at Lascaux—horses, bison, deer—and there are also verbs—to hunt, to die, to swim, and to walk.

I have taken the cave at Lascaux as the type specimen of Late Paleolithic art in southwestern Europe. Although it contains some of the finest examples so far discovered, it is far from being the only site and not even the oldest known.

Before Lascaux was discoverd in 1940, the most famous Late Paleolithic cave paintings were those of the Altamira cave in northern Spain. As was the case at Lascaux, it was discovered in 1868 by a dog, in much the same circumstances, but the paintings were not observed at that time.

> In1875 the cave was first explored by Don Marcelino S. de Sautuola, a pioneer of prehistoric studies in Spain. On a later visit in 1879 he was accompanied by his little daughter, who, penetrating by candle light into the chamber opening out behind the hall, was the first to discover the animal pictures on the ceiling and walls, to which she called her father's attention with a shrill cry of "Toros!" . . . although most of the polychrome frescoes represent bison, an animal long extinct in Spain, the paintings were generally considered to be the rude work of modern shepherds and his claims that they were of great antiquity met with universal scorn (Breuil and Obermaier, 1935, p.v).

Dogs and little girls are very important.

The ceiling of the Altamira cave is very low and thus the cave lacks the grandeur of Lascaux. Nevertheless it has magnificent paintings, which have been carefully reproduced by Abbé Breuil and Obermaier (1935). Nearly all are of large mammals: bison, horses, deer, ibex, and, less commonly, oxen, boars, elk, and wolf. The portrayals are generally a combination of incised outlines that are filled in with red, black, and other pigments.

This overwhelming concern at Altamira and Lascaux with the large mammals that provided the main source of food is not unique. Leroi-Gourhan (1967) analyzed the paintings of 72 Late Paleolithic caves, mainly in France and Spain. There are regional differences in the animals portrayed, correlated largely with the climate—glacial or interglacial—when the artists worked. Mammoths, for example, are found in the more northern caves and in the glacial rather than interglacial periods. The percentages in the total sample are: horse, 28; bison, 23; deer, 11; mammoth, 9; ibex, 8; ox, 6; human beings, 5—of which 82 percent are men. The other forms, each contributing less than 5 percent are cave lion, bear, rhinoceros, birds, fish, and monsters.

When all Late Paleolithic art forms are considered, that is, paintings, carvings, incised figures, and sculpture, the same themes dominate. There is an overwhelming concern with the larger mammals. Human beings are represented infrequently and, when they are, in a crude and often distorted manner. The human head, so important in later art, is sometimes so strangely portrayed in males that, had it not been attached to a body vaguely resembling that of *Homo sapiens*, proper placement in the scheme of classification would be in doubt. Females fared somewhat better in Late Paleolithic art. One common style is the Venus figurine. These are generally small sculptures—usually 4 to 10 cm rarely to 25 in height—and carved in stone, bone, or ivory. The females typically portrayed have huge breasts, hips, and buttocks and often small and nearly featureless heads. Many are clearly pregnant. Not surprisingly it is generally agreed that the Venus figurines are fertility symbols.

The Late Paleolithic objects that we identify as "art" may reflect a major change in the way our ancestors looked upon nature. Prior to these the artifacts so far discovered were strictly utilitarian. They consisted of weapons for hunting and protection as well as tools for domestic purposes: darts, spears, bows, arrows, clubs, axes, hammers, knives, scrapers, awls, and needles.

In Late Paleolithic times, when *Homo sapiens sapiens* arrived in Western Europe, something was added to culture that was not directly utilitarian. For whatever reason, these early people began to make objects that we call "art." A tool that has been engraved is no more effective than one which is not. And surely one cannot claim a direct utilitarian value for the painted walls of Lascaux or an ivory Venus figurine. Both may have had great symbolic value and, if so, that was innovative as well.

Whatever their motives might have been, those ancient human beings of 30,000 to 10,000 years ago left certain artifacts that transmit a new message. Stone axes and skin scrapers tell us very little about how Early Paleolithic Age people thought about nature, whereas cave paintings, carvings, and sculpture suggest a basic interest in food animals and the continuation of the human population. Surely these were not new interests in the Late Paleolithic but there are no data from earlier artifacts.

This overwhelming concern with food animals, as expressed in cave art, may be difficult for us to understand but consider the mode of life before the Neolithic period and the beginnings of agriculture. Food was obtained by hunting the game animals and by gathering whatever edible plant material was available—which would not have been much in the Ice Age. The main source was the larger mammals that were almost always stronger and swifter than the Cro-Magnon hunters. The hunt, therefore, was dangerous and although it generally ended with the death or escape of the hunted, that was not always the case. It could be the reverse. Remember also that only the crudest techniques for preserving food were available. Unless the hunt were successful, starvation was never more than a few weeks away. One lived, therefore, for the day, for on the morrow the everlasting quest for food must begin once more.

Life was surely uncertain and probably short—as it has always been for preliterate native peoples. It is likely that the size of the human population waxed and waned and only over vast periods of time was there a measurable increase. But the Paleolithic was closed by our most important cultural event—the beginnings of agriculture, an event that marks the onset of the Neolithic period. *Homo sapiens* began to settle in one place, establish villages, and later cities. Civilization was underway and with it came social stratification with growing inequalities, specialized occupations, new diseases, organized warfare, writing and literature, and improved technology (SAAWOK-II, pp. 525–577).

The onset of the Agricultural Revolution coincided with another revolution:

> One of the most profound revolutions in man's relation to the world began at the end of the paleolithic era: the dethronement of the animal. Up till then man had considered himself a minor creature, less powerful and less beautiful than his revered fellow creature the animal. With the domestication of certain animals and the later institution of a rigid social hierarchy, the animal was dethroned from its position of majesty. From then on, man was to consider himself the chosen master of creation .... The animal was first regarded as being higher than man himself: the sacred animal, the object of greatest veneration. During the paleolithic era—which was, above all, zoomorphic—the animal was the indisputable idol. This explains the great love and intensity of feeling emanating from animal representations (Giedion, 1962, p. 5).

REFERENCES: THE PALEOLITHIC VIEW OF NATURE

For the topic of Paleolithic art to be appreciated, it is absolutely essential that books containing color reproductions be consulted such as Bataille (1955), Breuil and Obermaier (1935), Leroi-Gourhan (1967), and Windels (1950). You will not regret doing so.

Adam (1963), Bandi *et al.* (1961), *Bataille (1955), Bégouën and Breuil (1958), Boas (1951), *Breuil (1952), Breuil and Obermaier (1935), Brodrick (1948), Daniel (1952), *Campbell (1983), Eliade (1978), Giedion (1962), Gowlett (1984), Grand (1967), Graziosi (1960), Grosse (1898), Hood (1978), James (1961, 1963), Joly (1891, ch. 5), Kozloff (1981), *Laming (1959), *Leroi-Gourhan (1967), Lommel (1966), Maringer (1960), Mazonowicz (1974), Moulin (1965), Pericot-Garcia, Galloway, and Lommel (1967), Pfeiffer (1982), Powell (1966), Raphael (1945), Ruspoli (1987), *Sanders (1985), Sieveking (1979), Torbrügge (1968), Ucko and Rosenfeld (1967), UNESCO (1954), Weltfish (1953), and *Windels (1950).

The extraordinary Paleolithic art of Europe is not geographically unique nor is it unique in style or subject matter. Similar work has been discovered throughout the world. Animals receive the most attention, both quantitatively and qualitatively. Some was done in prehistoric times and it is still being done today by some preliterate native peoples. A few references follow:

Asia. Brooks and Wakankar (1976), Neumayer (1983), and Sankalia (1978).

Africa. Brentjes (1970), Goodall, Cooke, and Clark (1959), Lajoux (1963), Lee and Woodhouse (1970), Lhote (1959), Maggs (1979), Ritchie (1979), Rudner and Rudner (1970), Stow (1930), and Willcox (1956).

The Americas. Cain (1950), Cressman (1937), Dewdney and Kidd (1962), Grant (1965, 1967, 1974), Heizer and Baumhoff (1962), Mallery (1886, 1893), Renaud (1936), Schaafsma (1971), Steward (1929, 1937), and Willoughby (1935).

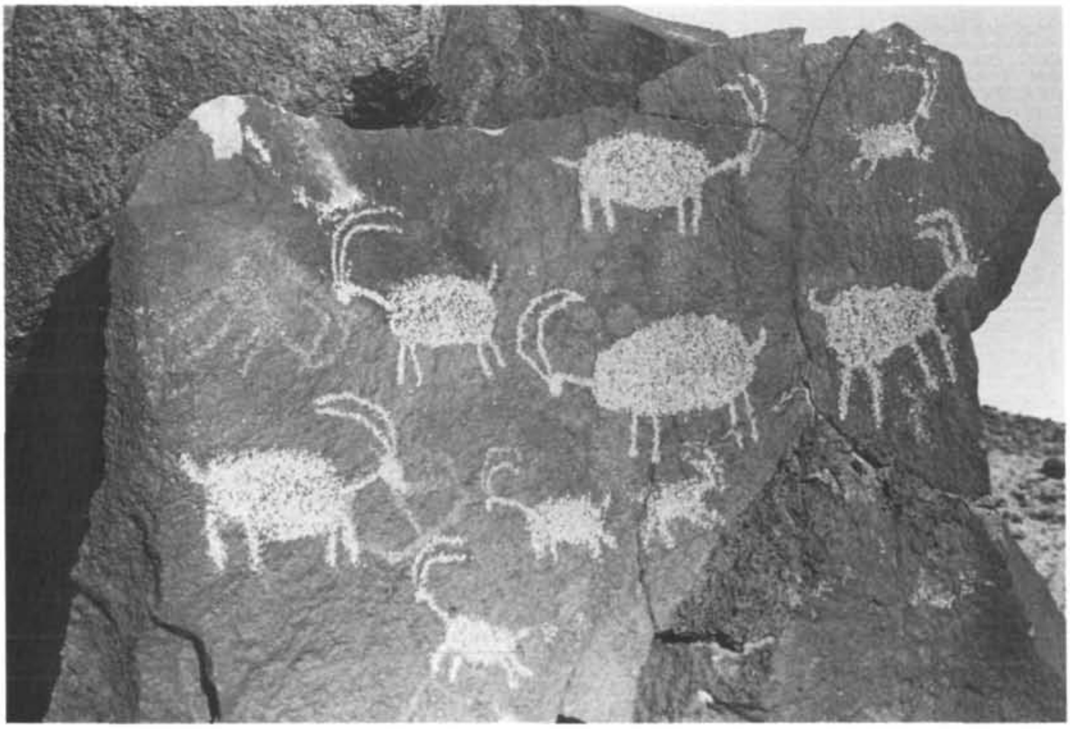
Australasia. D. Davidson (1936), Elkin, Berndt, and Berndt (1950), Spencer and Gillen (1899), Sterling (1896), Trotter and McCulloch (1971).

NATURE AND THE ANCIENT EMPIRES

The domestication of plants was the spectacular achievement of human beings at the onset of the Neolithic period. This new and more reliable source of food was seen as a gift of the gods, so it is not surprising that plants came to occupy an important position in religion. Myths to explain this beneficence have persisted to recent times:

> A rather widely disseminated theme explains that edible tubers and fruit trees (coconut, banana, etc.) were born from an immolated divinity. The most famous example comes from Ceram, one of the islands off New Guinea: from the dismembered and buried body of a semidivine maiden, Hainuwele, spring plants until then unknown, especially tubers. This primordial murder radically changed the human condition, for it introduced sexuality and death and first established the religious and social institutions that are still in force. Hainuwele's violent death is not only a "creative" death, it permits the goddess to be continually present in the life of human beings and even in their death. Obtaining nourishment from plants that have sprung from her own body is, in reality, to obtain it from the actual substance of the goddess. . . .
>
> A similar mythical theme explains the origin of food plants—both tubers and cereals—as arising from the excreta or the sweat of a divinity or mythical ancestor. When the beneficiaries discover the repulsive source of their foodstuffs, they kill the author; but, following his advice, they dismember his body and bury the pieces. Food plants and other elements of culture (agricultural implements, silkworms, etc.) spring from his corpse.
>
> The meaning of these myths is obvious: food plants are sacred, since they are derived from the body of a divinity. . . . By feeding himself, man, in the last analysis eats a divine being. *The food plant is not "given" in the world,* as the animal is.
>
> The first, and perhaps the most important, consequence of the discovery of agriculture precipitates a crisis in the values of Paleolithic hunters: religious relations with the animal world are supplanted by what may be called *the mystical solidarity between man and vegetation. . . .*

FIG. 4. Petroglyphs done by American Indians. Big Petroglyph Canyon, Naval Weapons Center, China Lake, California. These have been studied extensively by Philip J. Wilke who estimates that they range from a few hundred to a few thousand years in age. Nearly all shown here are mountain sheep. The styles vary. Those



shown in the upper left photograph have carefully rendered boat-shaped bodies with heads in nearly frontal view and with yoke-shaped horns. The sheep in the two other photographs have differently rendered bodies and the heads and elongated horns are shown in profile. A human being with a bow is shown at the lower left corner of the bottom figure on the facing page. The three smaller sheep at the bottom of that photograph and the two at the bottom of the photograph above may be kids, done by Indian children. Note the vague, almost invisible, petroglyph centered among the four sheep in the upper left photograph and in front of the upper left sheep in the photo above. These are much older than the others, having been covered by "desert varnish," which may be deposited on exposed rocks in arid regions.

> Since women played a decisive part in the domestication of plants, they became the owners of the cultivated fields. . . . The fertility of the earth is bound up with feminine fecundity; hence women become responsible for the abundance of harvests, for they know the "mystery" of creation (Eliade, 1978, pp. 38–40).

The first half of the Neolithic period was preliterate, so we must continue to rely on artifacts for suggestions of how human beings looked upon nature. We can supplement these data with information about the beliefs of preliterate native peoples that have survived to recent times (Fig. 4), such as the example just given. To a certain extent the conclusions based on these two sources can be checked by the written information that became available later in history. The reasoning here is, since nature is so intimately associated with religion and religion such a highly conservative institution, what was put down at the dawn of writing probably reflected beliefs of great antiquity.

MESOPOTAMIA

By approximately 3000 B.C., symbols that were used millennia before, such as those in cave paintings and engravings on stone and bone, had evolved into the cuneiform writing of the early Sumerians. This had been a slow evolution that began as a crude drawing, for example of a horse, and ended as a group of wedge-shaped incisions on a tablet of wet clay. Those incisions would have lost all resemblance to a horse. Nevertheless, each group of incisions would have a constant relation to some thing, and hence would serve the vital functions of communication and preservation of information. These cuneiform tablets were dried and became most durable—quantities remain to this day.

It required another millenium and a half, to about 1400 B.C., before a true alphabet appeared, that is, a small group of symbols that could be combined in endless ways to express ideas and represent things. What began as a picture of a horse became the equivalent of "H-O-R-S-E" in an evolution that required many millennia. The economy of an alphabet is tremendous. Those five letters can be combined in innumerable ways to convey bits of very different information: she, rose, ore, sore, shore, her, etc.

Thus it became possible to express complex ideas in writing and to communicate them widely to others who had the ability to read and understand. The vocabulary of preliterate people was probably very small but, once writing became widespread, it would have become much richer. For those who are interested, literacy is autocatalytic.

The Sumerians and other people of ancient Mesopotamia have left us a rich literature that tells us how they looked upon nature. In this region dominated by the Tigris and Euphrates Rivers, there are the remains of the oldest known civilization—that of the Sumerians. Their civilization antedates that of Egypt, China, and the Indus Valley. It is also the civilization that, more than any other, influenced Western Civilization.

And what do we find?—a belief system in which nature is divine and accepts that human beings and other creatures were created by divine forces. It may be difficult for those trained in modern science to comprehend the nature of "belief" five thousand years ago. The sciences make a sharp distinction between what is "natural" and what is "supernatural." The first refers to the objects and processes that obey the impersonal laws of nature as they apply to living organisms. These laws involve constant relationships between causes and effects. They are invariant—given the same circumstances and conditions, a given cause will be followed always by a given effect. Neither human desires nor forces outside of nature can affect that outcome.

We contrast this way that scientists look upon nature with explanations that involve supernatural forces that may be capricious and, so, do not obey invariant rules. These can never be studied by the basic approaches of science: observation and experiment. We are here in the realm of belief, not rational science. This is the pattern of belief that has characterized the human mind over all of its history. It is a comforting belief for many to accept that there are forces far more powerful than those available to human beings that control the destinies of individuals and nations. This is a mind-set, however, that has been singularly unsuccessful in furthering an understanding of natural phenomena—the task of science.

Nature and the divine were essentially the same for the Sumerians. All nature—sea, air, land, and sky—had a divine counterpart. Each city had its protecting god or goddess. Anum was the father of the gods. He was portrayed as a bull whose bellowing was thunder and whose semen was rain. His wife was Antum, a cow whose udder was the clouds and whose milk was rain. Enlil, a most important god, brought the moist spring breezes that were so important for agriculture. Enki was god of fresh water and, hence, also necessary for the growth of crops.

There were many other gods and goddesses. In fact, the Sumerians appear to hold the world's record. Their pantheon numbered about 5,000 deities. Inanna was the goddess of date groves, sheepfolds, harlots, and war as well as the planet Venus and of love. It is probable that she, as well as other deities, had an extremely ancient history—going back to Paleolithic times. The antecedents of Inanna are to be found in the Venus figurines of the Late Paleolithic and she is worshipped in later centuries and by different peoples as Ishtar, Ashtarte, Aphrodite, and of course Venus. Thus that basic characteristic of life, reproduction, is guided by the divine.

FIG. 5. Scene from the Babylonian story of creation. Marduk is pursuing Tiamat. (From George Smith *The Chaldean Account of Creation,* 1876.)

It is interesting to note the Mesopotamians did not believe that the world was eternal—instead it had been created. Human beings were also created and there were several suggestions for how this might have been accomplished: from the mixing of the blood of two gods; molded from clay by a god; from sprouted seeds; or formed directly by a goddess.

The most famous of the Mesopotamian documents showing how nature was believed to have come about is the Baby-

FIG. 6. Another version of Marduk about to slay Tiamat. Tiamat is shown as a serpentine dragon. This is a photograph of an impression of an Assyrian cylinder seal (9th to 8th century B.C.). (From *The Great King of Assyria,* Metropolitan Museum of Art, 1945.)

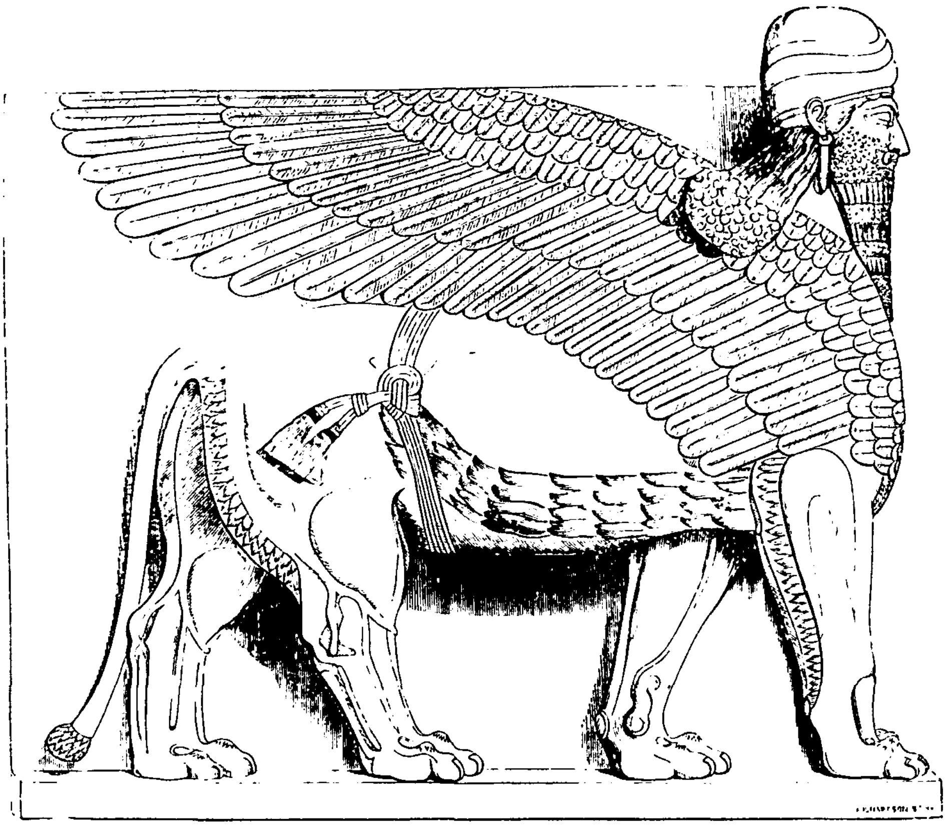
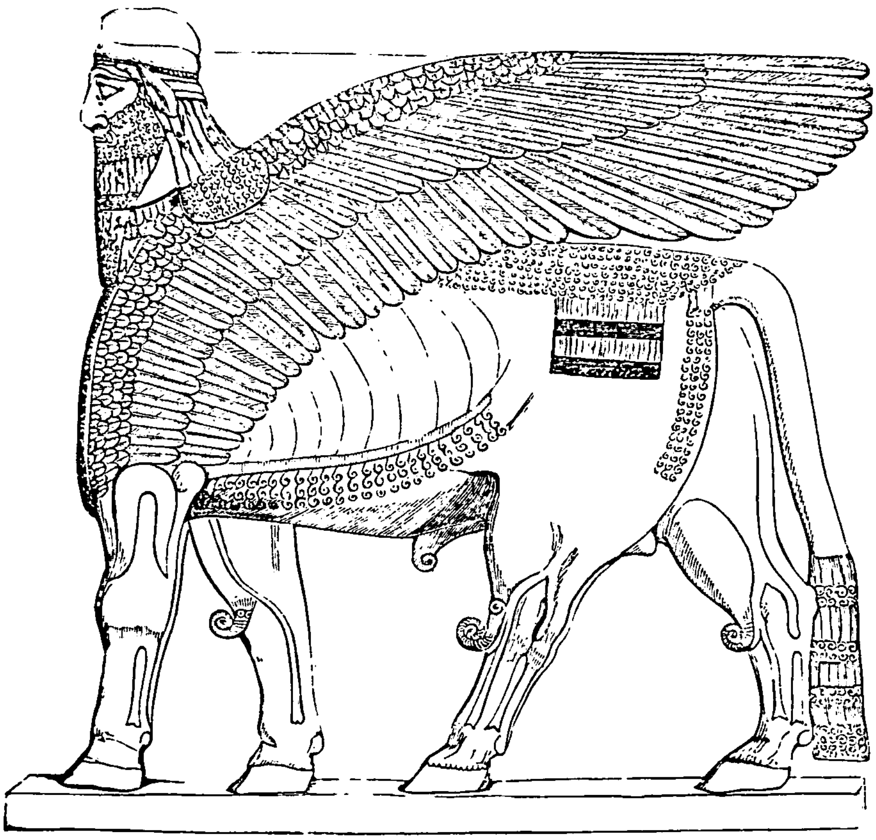


FIG. 7. Guardians of the Palace of Ashurnasirpal II (9th century B.C.) at Nimrud in what is now northern Iraq. At the left is a winged lion with a human head and at the right a winged bull, also with a human head. The illustrations are taken from the report of the discoverer, Sir Austen Henry Layard (*Nineveh and Its*

lonian creation myth, *Enuma Elish.* It was written down by a Semitic people, the Akkadians, who conquered the Sumerians. The first divine couple was the male Aspu and the female Tiamat. She was often portrayed as a dragon. Later numerous other gods appeared, including Marduk (Figs. 5–6). Eventually there was trouble and even the gods had to resort to conflict to settle their disputes. Two factions formed, one taking Marduk and the other Tiamat as their leader. Battle was imminent and it was agreed that the outcome would be decided by single combat between the leaders. The conflict that was to change all history began. Tiamat was about to swallow Marduk but he caused the winds to blow into her mouth and distend her body. With Tiamat thus incapacitated, Marduk shot an arrow into her heart and eviscerated her. He then cut her into halves—one half becoming the dome of the sky and the other the earth.

The Sumerians' religion has many counterparts with events described in the Old Testament. There was an evil serpent who tried to produce chaos in the world; there was a deluge but this one resulted in the extermination of all so that repopulation was necessary; Enki ate a forbidden fruit and lost immortality.

Since obvious causes of sickness were not apparent, and since that basic compulsion of human beings to understand could not be satisfied, by default the cause was placed in the hands of unknowable forces—the gods. Sickness, therefore, was a sign of divine displeasure. Sickness was to remain



Remains, 1849, Putnam, New York; the title is in error. Layard first thought he had discovered Nineveh but later the site was found to be that of Nimrud). A pair of these statues is now in the Metropolitan Museum of Art in New York City.

a great mystery until the discoveries of scientists such as Pasteur, Koch, and Semmelweis—more than five millennia in the future.

It is highly probable that this point of view was basically the teachings of the priests—a group of individuals who assigned themselves the tasks of explaining the will of the gods, which they alone could understand, to just plain ordinary folks and exacted suitable payments for these services. One way to seek the return to health, therefore, was to propitiate the gods with the help of the good services of the priests.

But another way was practiced as well and this eventually evolved into rational medical practice. This involved the direct intervention by physicians. To a person bleeding from a deep wound it might seem more appropriate to try to stem the flow personally or to seek the help of another, a physician, rather than ask the gods to do it.

Each of these two modes of dealing with medical problems had their professionals, especially in Akkadian times. The *asipu* physician examined the patient for possible omens and then decided how the gods were to be propitiated and the causative agents, evil spirits, exorcised. The *asu* physician, on the other hand, sought relief for his patient through the use of drugs and other medical procedures.

Sumerian texts exist that list various drugs that were used in the treatment of various ailments. Kramer describes a cuneiform tablet dating to the end of the third millennium B.C. (that means

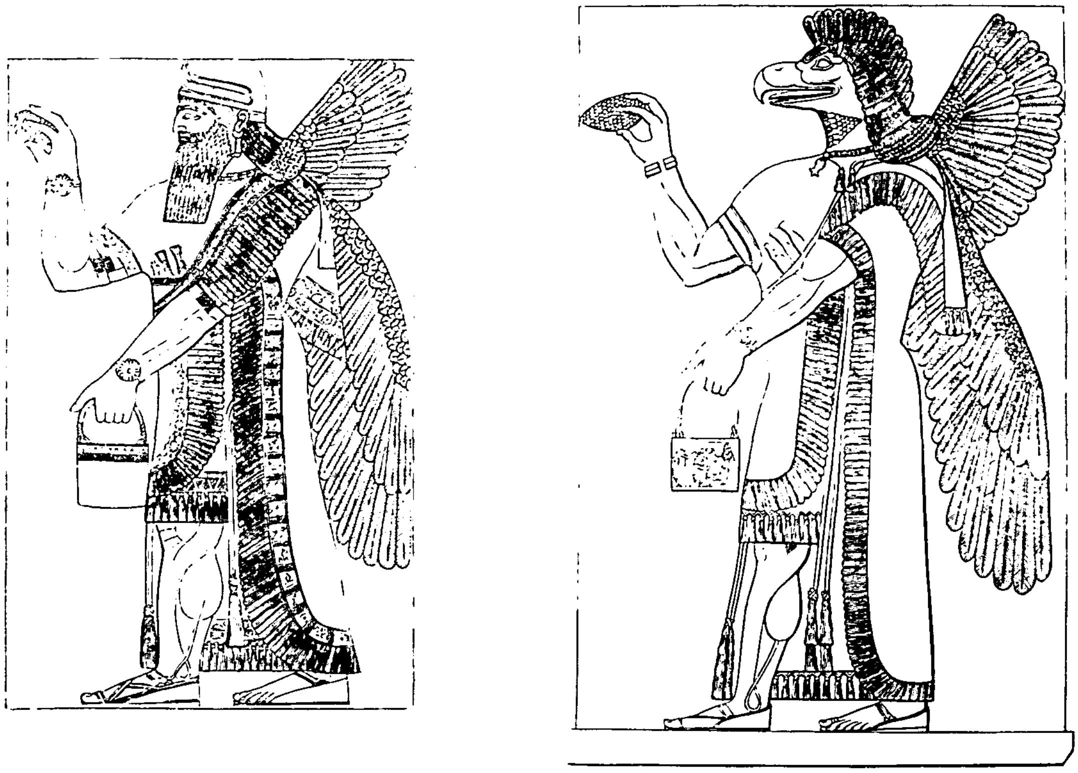


FIG. 8. Human-animal figures from two slabs carved in low relief. These were also discovered by Layard in Ashurnasirpal's Palace at Nimrud and are from the book cited in the caption of Figure 7.

approaching 2000 B.C.) as "The First Pharmacopoeia," and writes:

> The Sumerian physician, we learn from this ancient document, went, as does his modern counterpart, to botanical, zoological, and mineralogical sources for his materia medica. His favorite minerals were sodium chloride (salt) and potassium nitrate (saltpeter). From the animal kingdom he utilized milk, snake skin, and turtle shell. But most of his medicinals came from the botanical world, from plants such as cassia, myrtle, asafoetida, and thyme, and from trees such as the willow, pear, fir, fig, and date. These simples [products of medicinal plants] were prepared from the seed, root, branch, bark, or gum, and must have been stored, as today, in either solid or powdered form. The remedies prescribed by our physician were both salves and filtrates to be applied externally, and liquids to be taken internally (Kramer, 1959, p. 61).

One prescription reads as follows:

> Pour water over a dried and powdered water snake, the *amamashumkaspal*-plant, root of the thorn plant, powdered *naga* [a plant yielding alkali], powdered fir turpentine, faeces of bat, after having heated, with this liquid wash [the affected spot] and after having washed with the liquid rub with oil and cover with *shaki* (Hawkes, 1973, p. 233).

The gods were also responsible for the harvest. Their intercession was sought for the desirable climatic conditions necessary for plant growth and for the control of pests. The Sumerians were talented agriculturalists and developed a complex technology for irrigation. The bounty of their farms made possible the support of an urban population and, hence, civilization.

Looking backward over human history, one of the most interesting observations is the slow progress in those aspects of civilization that are science-based. Take medicine, for example. The Sumerian physicians, at the dawn of literate history, used techniques that were much the same as those of the Western World until a few centuries ago, and to this day medicine based on a useful knowledge of the causes of disease is still in an active stage of development. Until quite recently our pharmacopoeia was also based mainly on plant products. The same remains true for many native peoples. And, seemingly, the supernatural approach continues in all cultures with appeals for divine intervention for the sick.

So much of what we are and do today appears to trace back to the very beginnings of civilization in Sumeria. We credit the Sumerians with many innovations. They were most surely a talented and inventive people but much of what they did must have been inherited from their preliterate ancestors. We base our opinions of the past mainly on the written record that has endured. No pre-Sumerian written record has been discovered but I believe we can assume that they transmitted the accomplishments of their preliterate ancestors along with their own.

EGYPT

Sumeria and Akkad came into history, had their remarkable, though brief, period of eminence, and vanished into the desert sands. Egyptian civilization, on the other hand, began almost as early as that of Sumeria and was impressive from about 3500 B.C. to the time of the Roman conquest beginning in 58 B.C. (in the days of Julius Caesar, Cleopatra, Antony, Pompey, etc.). Consequently far more data exist that will allow us to reconstruct the Egyptian view of nature and we find the familiar association of religious beliefs and animals as well as the use of animal symbols in Egyptian hieroglyphic writing.

> The relationships between gods and beasts were as intimate as they were ancient, and all kinds of creatures both wild and domestic were kept in temples for cult purposes. So, too, thousands upon thousands of carefully embalmed bodies of all these cultic species from cats to crocodiles went into vast animal cemeteries. If one is looking for ways in which peoples differ from one another, zoomania can be recognized as an Egyptian peculiarity (Hawkes, 1973, p. 339).

Let's hear it from the Father of History:

> There are not a great many wild animals in Egypt, in spite of the fact that it borders on Libya. Such as there are—both wild and tame—are without exception held to be sacred. . . . The various sorts have guardians appointed for them, sometimes men, sometimes women, who are responsible for feeding them; and the office of guardian is handed down from father to son. [The peoples'] manner, in the various cities, of performing vows is as follows: praying to the god to whom the particular creature . . . is sacred, they shave the heads of their children—sometimes completely, sometimes only a half or a third—and after weighing the hair in a pair of scales, give an equal weight of silver to the animals' keeper, who then cuts up fish (the animals' usual food) to an equivalent value and gives it to [the animals] to eat. Anyone who deliberately kills one of these animals, is punished with death; should one be killed accidentally, the penalty is whatever the priests choose to impose; but for killing an ibis or a hawk, whether deliberately or not, the penalty is inevitably death (Herodotus, 1954, pp. 127–128).

These seemingly severe penalties must be related to what the animals represent. The ibis was regarded as the incarnation of the god Thoth. Thus ibicide was deicide. Thoth was the god of the moon and of great importance to scholars—being the god of learning, writing, and chronology.

The falcon was sacred to the main deity, Horus, as well as the symbol of the pharaohs. It is not surprising, therefore, that death was the penalty for killing a falcon. Horus was god of the sky, whose outstretched wings protected the earth. At times his eyes were regarded as the sun and the moon.

The Egyptian pantheon was enormous. Different cities had their endemic gods and

FIG. 9. Human-animal figures in Egyptian sculpture. The sphinx has a complex symbolism that has varied with space and time: power, vigilance, virtue, etc. But above all the sphinx symbolizes enigmatic wisdom and ultimate meanings. This figure and the next two are from the classic work by George Perrot and Charles Chipiez, *A History of Art in Ancient Egypt* (1883). Many of the things they illustrate were obtained during Napoleon's ill-fated expedition to Egypt (1798)—the army was accompanied by a corps of scholars who were responsible for the first large scale explorations of Egyptian antiquities. Among other things they discovered the Rosetta Stone but it was later captured by the British.

conquest tended to make matters complex—some of the gods might be forgotten, while others were adopted by the conquerers. In addition, the symbolism and nature of the gods changed over time, of which Egyptian civilization had a very great deal.

Seemingly every common species of animal was associated in some way with the gods (Figs. 9–11). The cobra appears as an emblem, the uraeus, on the headdress of the pharaohs and was a symbol of sovereignty. The ram was the symbol of one of the most ancient of all the gods, Amun, who at various times was regarded as the god of water, the god of fertility (hence the ram), the sun god, and finally, as the soul present in everything. The jackal was associated with Anubis, the god of the dead. Seth began as a respectable deity but later became associated with evil. He controlled the desert and hence was an enemy of vegetation. In a battle with the god Horus, he lost his testicles. His main symbolic animal is imaginary but other species such as the crocodile, fish, ass, pig, and hippopotamus are associated with him. Bees were the tears of Ra, the sun god. Bulls had various symbolic meanings, including being the soul of Ptah. Ptah did all sorts of things: invented crafts and created life. There were four god-animals associated with the canopic jars into which the internal organs were placed when a body was embalmed. A falcon jar held the intestines; an ape jar, the lungs; a jackal jar, the stomach; and a jar decorated with a human head held the liver. This fascinating list could go on and on.

It is interesting to speculate about what the Egyptians "really believed" to be the

FIG. 10. Egyptian deities. The goddess Bast (left) and the goddess Isis-Hathor (right).

relation of animal to god. Many, especially the more superstitious and illiterate people, may have assumed a near identity, especially if death was the sentence for killing the god's symbolic species. The priests may have had a more intricate opinion:

> Only rarely was the god regarded as the animal itself, except, for example, in times of religious decline. The individual animal was only an earthly image of the transcendent primeval image, the theriomorphic form of which expressed some particular aspect of a divine entity. Sacred animals were, therefore, the 'eternal soul' (as the ethnologist Frazer described it) or, as the Egyptians would say, the *ba* of the gods. The ram was the

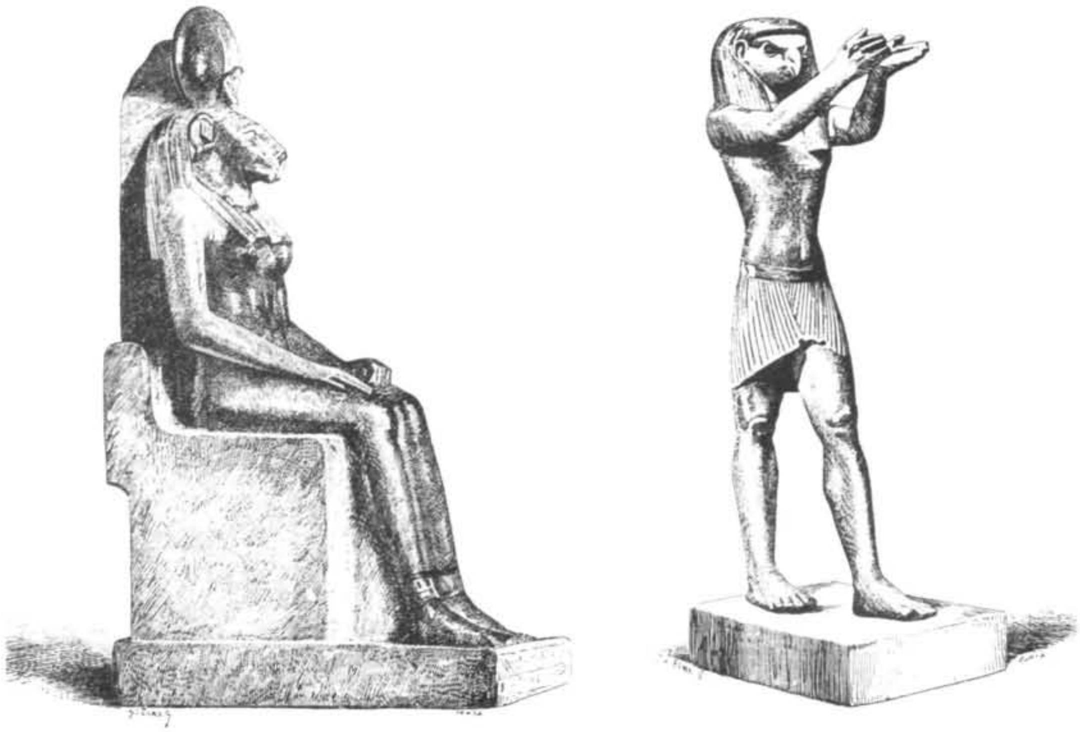


FIG. 11. Egyptian deities. Sekhet (left) and Horus (right).

soul of Amun-Re, the Apis bull that of Ptah, and the crocodile was the *ba* of Suchos (Lurker, 1980, p. 26).

Although only Sumeria and Egypt have been given as examples of the deification and extensive symbolic use of the phenomena of nature, and especially of animals, these practices were universal in ancient times (Figs. 7–8). In some cultures, however, there was a trend toward reducing the pantheon from thousands to a few or even one main god, for example, among the ancient Jewish people. There was also a trend toward reducing the close relation with animals and natural things and processes.

However, to this day the Christian religion has vestiges of polytheism and animal symbolism. In monotheistic Christianity, the Deity consists of three entities, two of them in human form, and especially in the Latin countries the adoration of the numerous saints by ordinary people seems not to differ from worship of divine beings. Seemingly monotheism is by edict, not actuality.

Animal symbolism remained strong until modern times. In churches throughout Italy, Spain, and France—those not scoured by the fury of the Reformation—animals abound (Figs. 12–14). A lamb in sculpture or mosaic symbolizes Jesus. Three evangelists are represented by animals: John by an eagle, Mark by a lion, and Luke by an ox. The fourth, Matthew is represented by a man. At times the mammals are shown with wings. The iconography of Western religious art of the Romanesque and Renaissance periods is complex and fascinating and it shows strong connections with the most ancient belief systems. See, for example, Clement (1875), Didron (1851), Ferguson (1954), and *Hall (1974).

REFERENCES: THE VIEW OF NATURE IN ANCIENT EMPIRES

Breasted (*1909, 1912), Budge (1904, *1926), Cerný (1952), Childe (1942), Cirlot (1972), Doris and Lenowitz (1976),

FIG. 12. The Abbey Church of S. Antimo at Montalcino, near Siena, Italy. This Romanesque church was begun in the 9th century but most of the structure dates to the 12th century. There is an abundance of animal sculpture and a few examples are shown on the next two pages.

Frankfort (1949, 1951), Frankfort *et al.* (1946), Ghirshman (1954), Gray (1969), *Hawkes (1973), *Hawkes and Woolley (1963), Heidel (1951), S. H. Hooke, (1953), Hopfner (1913), Jacobsen (1976, 1987), Kramer (1959, 1961, 1972), Kramer *et al.* (1969), *Langdon (1964), *Lesko and Redford (1987), Lurker (1980, Müller (1964), Oppenheim (1964), Pritchard (1969), Ringgren (1973), Sandars (1964), Thorwald (1963), and Wiedermann (1897).

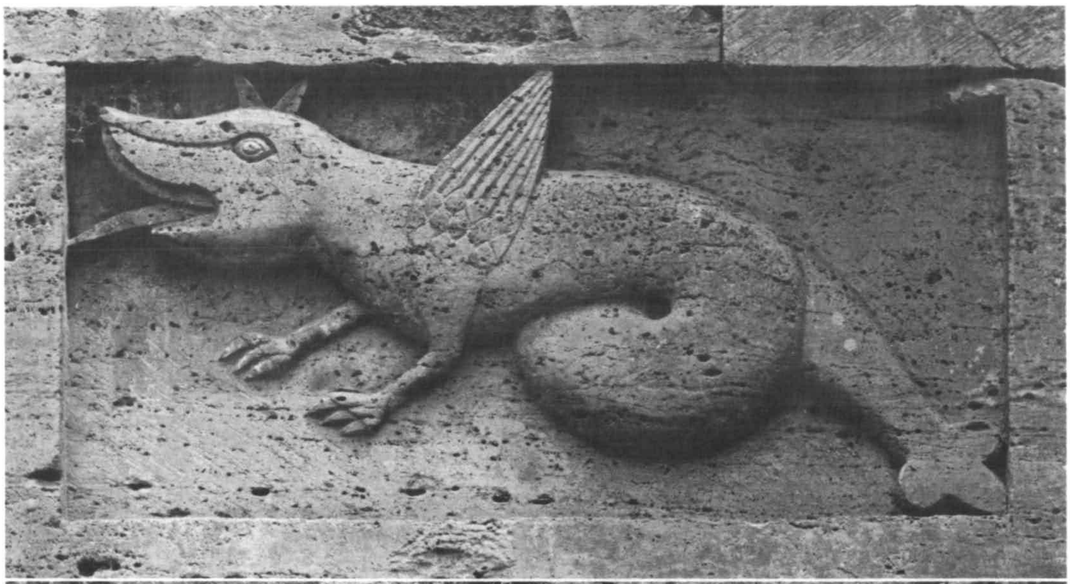
THE GREEK VIEW OF NATURE

. . . Or how Aristotle tried to put it all together.

The first three millennia of literate life were dominated by Oriental Civilizations—Egypt and a sequence of empires in the Near East and Asia. Thereafter an event occurred that was seminal for Western Civilization and provided a new way of looking at nature.

Edith Hamilton begins her lyrical and insightful *The Greek Way* (1942) as follows:

> Five hundred years before Christ in a little town on the far western border of the settled and civilized world, a strange new power was at work. Something had awakened in the minds and spirits of the men there which was so to influence the world that the slow passage of long time, of century upon century and the shattering changes they brought, would be powerless to wear away that deep impress. Athens had entered upon her brief and magnificent flowering of genius which so molded the world of mind and



of spirit that our mind and spirit to-day are different. We think and feel differently because of what a little Greek town did during a century or two, twenty-four hundred years ago. What was then produced of art and of thought has never been surpassed and very rarely equalled, and the stamp of it is upon all art and thought of the Western world. And yet this full stature of greatness came to pass

FIG. 13. Animal symbolism. The peacocks above are from the iconostasis (11th century, possibly from Constantinople) in the Duomo of Torcello, near Venice, Italy. In Christian art the peacock is a symbol of immortality since its flesh was thought not to decay. The grape leaves are symbols of the Eucharistic wine and the peacocks are drinking from an elongate chalice. The symbolism is that those who participate in the Eucharist will have immortality, as do the peacocks. The photographs on the right are of pre-Renaissance griffins. The top one guards the entrance to the Duomo in Ferrara (begun in 12th century), Italy. The lower one, probably of Byzantine origin and brought home by the Crusaders after the sack of Constantinople, is in the south facade of San Marco in Venice, Italy. Griffins had a bird's head and wings on a lion's body. They had several very different symbolic meanings: Christ, a guardian, evil, and those who persecute Christians.

at a time when the mighty civilizations of the ancient world had perished ... (pp. 15–16).

[That] ancient world, in so as we can reconstruct it, bears everywhere the same stamp. In Egypt, in Crete, in Mesopotamia, wherever we can read bits of the story, we find the same conditions: a despot enthroned, whose whims and pas-

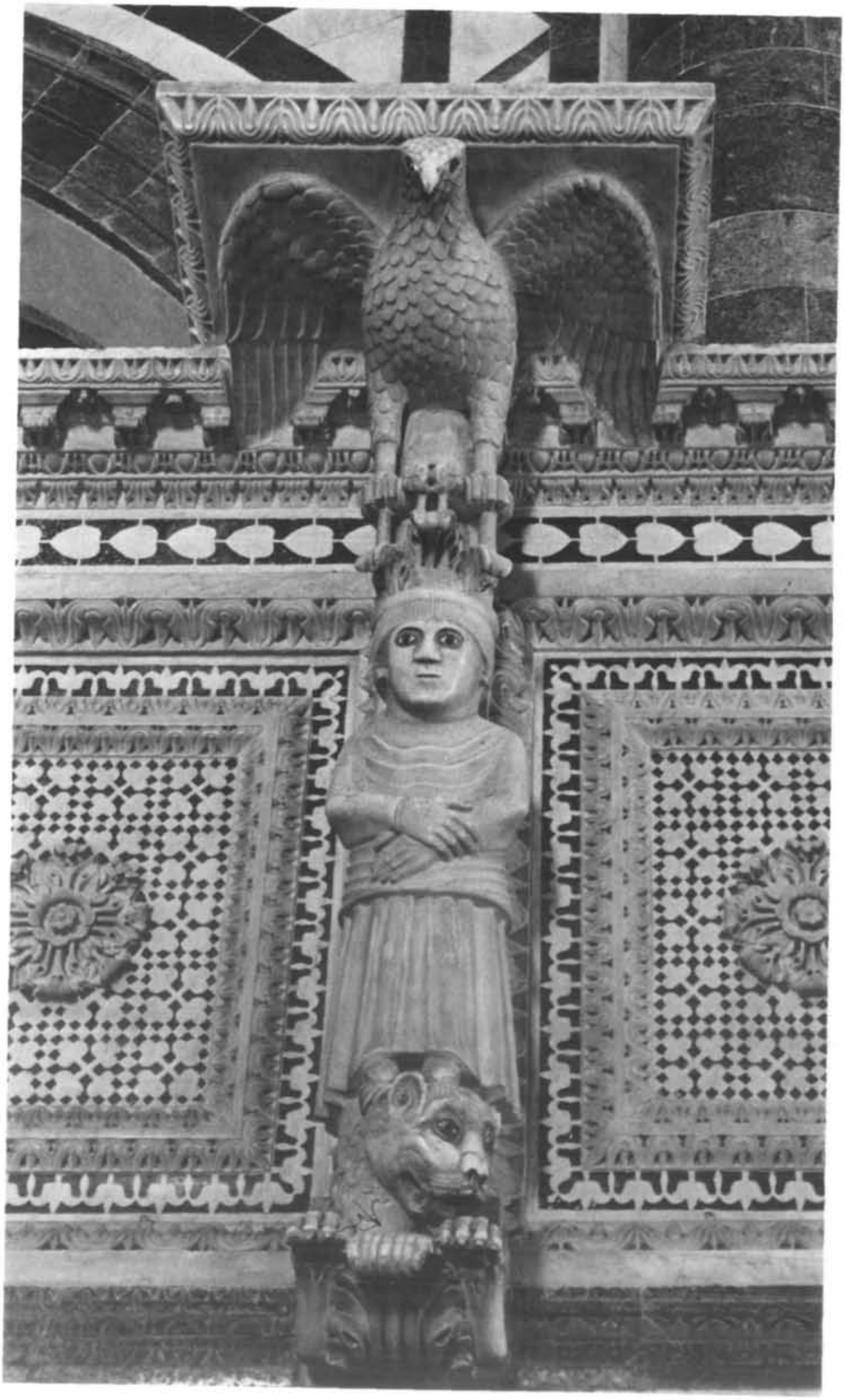


FIG. 14. Nature in Christian art. The left photograph is of the pulpit of San Miniato (13th century) in Florence, Italy. An eagle holds a base for the bible and a lion is at the feet of the human figure. Note the abundance of plant motifs in the panels to either side. The upper photograph shows a bull holding a book—symbolizing St. Mark with his gospel. This is a ceiling mosaic from the Archiepiscopal Chapel (end of 5th century A.D.) in Ravenna, Italy. Below is a mosaic, from the Arian Baptistry (end of 5th century A.D.) in Ravenna, showing a baptismal scene. The figure at the left symbolizes the River Jordan. Note the river flowing out of the jug at the right elbow of the river god.

FIG. 15. The lions of Delos, an island in the Aegean Sea east of mainland Greece. This is one of an avenue of archaic statues (7th century B.C.) of lions. The artists of the Greek world portrayed animals in a far more realistic manner than did those of Egypt or other empires of the Near East. Whereas the non-Greeks produced many chimeras combining the parts of animals and human beings (Figs. 7–11), such was infrequent in Greek art. Delos was settled by the Ionian Greeks and was an important religious center. After 426 B.C. no one was allowed to be born or die there (for the latter they were taken to a nearby island).

sions are the determining factor in the state; a wretched, subjugated populace; a great priestly organization to which is handed over the domain of the intellect (pp. 18–19).

None of the great civilizations that preceded [the Greeks] and surrounded them served them as model. With them something completely new came into the world. They were the first Westerners; the spirit of the West, the modern spirit, is a Greek discovery and the place of the Greeks is in the modern world (p. 19).

A biologist seeking intellectual forebears feels at home when reading the works of Aristotle. No such feeling accompanies the reading of earlier descriptions of how nature was perceived. With the Greeks the analysis becomes rational and the data empirical to a degree that suggests the metaphor of a mutation. Compared with what went before, mature Greek thought *is* different. Gone are the demons of creation and gone are the supernatural causes of natural phenomena. We find instead attempts, primitive and premature as they often were, to explain natural phenomena in terms of rules and regularities that derive from nature itself. Nature is interpreted in terms of nature, not by superstition and flights of fancy of the human mind (Fig. 15).

In the Western World science was underway. It was not to banish other systems of thought, however. Much of today's conflicts are the consequences of the two dominant and antagonistic patterns of thought that we have inherited—an Oriental religion based on what is supernatural or revealed contrasted with Greek science with its emphasis on data, observa-

FIG. 16. Mosaic floor with a winsome sea creature at Ostia Antica, the seaport of ancient Rome (since silted up). This is part of a very large mosaic from the Baths of Neptune, which were erected in the reign of Hadrian, Roman Emperor from 117–138 A.D. The figure at the right is not Neptune but one of his marine associates.

tions, natural causes, and verifiable conclusions.

The most notable Greek biologist was Aristotle, student of Socrates and teacher of Alexander the Great. He was born in 384 B.C. and died in 322. He spent much of his life in Athens. Last year's Essay (SAAWOK—IV, pp. 420–428) discusses his contributions to developmental biology as well as to the beginnings of naturalistic thought among the Greeks. He is justly considered the Father of Embryology and there is ample reason to extend that appellation to animal biology as a whole. This year we will consider only Aristotle's contributions to animal form and function.

We start the science of animal biology with Aristotle because he was the first to ask the sorts of questions, seek the necessary sorts of data for answers, and to provide the type of answers that we employ in science to this day. He provided a pattern for learning about the natural world, which is among the most difficult of all steps in science. It is a matter of being able to ask a question in such a manner that data can be sought for the answer.

All initiators of paradigm shifts in science face a fundamental difficulty: to propose a new conceptual framework when there is already one accepted by most and hallowed by tradition. In Aristotle's case this may not have been much of an obstacle—there was not all that much to hallow. Aristotle refers to a few other students of nature but we know little about them except for what he tells us. To us it appears that Aristotle effectively began biology—and that was the opinion of ancient scholars in a better position than we to judge.

What did he do?

HISTORIA ANIMALIUM

Historia Animalium is the oldest extant monograph of general zoology. It is sometimes described as a loosely organized collection of information about animals—a 4th century B.C. Parker and Haswell. *His-*

toria Animalium does contain a tremendous amount of information as well as an intimation that Aristotle knew far more than he wrote.

In contrast with biological publications of today, it does seem rather loosely organized since it covers everything he knew about all species. *Historia Animalium* begins the analysis as though there is no science of holistic biology, which of course was true, and proceeds to develop one. Some of the things that were problems for him are no longer problems for us—they have become part of our conceptual framework and are taken for granted.

Nevertheless, those likely to read this Essay will find it fascinating to open *Historia Animalium* almost at random and start reading—especially the translation of D'Arcy Thompson. The experience is not unlike that of a biologist's first reading of Charles Darwin's *On the Origin of Species.* In each case one will be constantly amazed at the things they knew and the questions they asked. "How could they possibly have thought of that?" Both works are as instructive for showing how fine, disciplined minds work as they are for the subject matter.

The first few paragraphs of *Historia Animalium* begin the analysis of some very fundamental problems (486^a and 486^b). (These are the standard notations introduced in the Bekker edition of Aristotle's works and followed subsequently in Thompson's 1910 translation and Peck's 1965 and 1970 translation. Peck's version is especially useful since Greek and English are on facing pages and the reader can check for himself the accuracy of the translation. The quotes to follow will be from Thompson.)

Aristotle notes that the parts of animals are of two sorts. *Composite* parts are those that cannot be divided in such a manner that two basically identical parts result. The hand and the face are examples. All composite parts are composed of *simple* parts. These can be divided and the resulting halves will be essentially the same. Flesh, bone, and sinews would be examples.

> All those parts that do not subdivide into parts uniform with themselves are composed of parts that do so subdivide (486^a, 13).

This is an important concept: different complex structures are built from varying combinations of the same building blocks. This has been a powerful notion throughout the development of the science of biology but especially so in the last two centuries. In the early 19th century Schleiden and Schwann proposed that the bodies of all organisms are composed of the same building blocks—cells. Later the basis of Mendelian inheritance—genes situated on chromosomes—was found to be essentially the same in all organisms no matter how they might differ in form and function.

Next Aristotle notes that some individuals resemble one another in all their parts: "One man's nose or eye resembles another man's nose or eye." Such individuals are members of the same kind or species.

There are also categories of individuals that resemble one another less closely, their parts being noticeably different. Some birds, for example, have long bills, others short; some have many feathers, others fewer. Such individuals can be said to belong to the same "genus," such as "birds" or "fishes."Aristotle is using "genus" not in the present day sense but for a larger category—birds and fishes to us are different Classes of vertebrates. (Aristotle did have the concept of hierarchical classification as we shall see shortly.)

Aristotle sought also to compare individuals that belong to different "genera." Although they might be similar in some respects their resemblances are merely analogous: "for what the feather is to a bird, the scale is to a fish" (486^b, 21).

Here we have the onset of a way of thinking that was to develop as one of the most important concepts relating to structure: homology *vs.* analogy. Aristotle realized of course that there was variation among those human noses, yet basically they were the same structure. We would say they are homologous structures. Although both feathers and scales have the same general function—covering the individual—Aristotle viewed them as being somehow different. They might have the same function, covering the body, but not the same structure. We, too, now call them analogous structures. This line of reasoning remains useful to this day. Consider this prophetic comparison of the paired appendages of birds and fishes:

> Birds in a way resemble fishes. For birds have their wings in the upper [=anterior] part of their bodies and fishes have two fins in the front part of their bodies. Birds have feet on their under [=posterior] part and most fishes have a second pair of fins in their under-part and near their front fins (*Progression of Animals*, 714^b, 4).

Aristotle then goes on to make sense of the different ways animals live (487^a, 15ff.). Some animals live on land and others in water. Those which live in water show two basic patterns. Some, the fishes, take water in and pass it out over the gills. These always feed in water and do not come out on land. Other species—crocodiles, otters, beavers—do not have gills through which water passes in and out. They may obtain their food in water but they come out on land to breed.

> Some land animals—human beings, for example—breathe but others that have notches on their bodies—the insects—do not.
>
> Furthermore, some animals are stationary, and some move about. The stationary ones are found in water; no land-animal is stationary (487^b, 6; Peck's translation).

Just try to imagine what breadth of knowledge is necessary for Aristotle to make such a statement. A similar broad generalization is,

> But no creature is able only to move by flying, as the fish is able only to swim, for the animals with leathern wings [*i.e.*, as in bats] can walk (487^b, 23).

The whole thrust of these opening sections of *Historia Animalium* is to reduce the great diversity of natural phenomena to a comprehensible conceptual scheme. Aristotle sought unifying themes without which rational thought is difficult.

It requires considerably more analytical ability to understand any basic similarity of the structures associated with food in view of the great variations.

> Common to all animals are the organs whereby they take food and the organs whereinto they take it; and these are either identical with one another, or are diverse in the ways above specified: to wit, either identical in form, or varying in respect of excess or defect, or resembling one another analogically, or differing in position. Furthermore, the great majority of animals have other organs besides these in common, whereby they discharge the residuum of their food. . . . Now the residuum of food is twofold in kind, wet [urine] and dry [fecal material], and such creatures as have organs [bladders] receptive of wet residuum are invariably found with organs [intestines or bowels] receptive of dry residuum; but such as have organs receptive of dry residuum need not possess organs receptive of wet residuum (488^b, 29–489^a, 4).

Here are a few more quotations that show something of the range of matters discussed in *Historia Animalium.*

> All flying creatures possessed of blood have feathered wings or leathern wings; the bloodless creatures have membraneous wings, as insects (490^a, 8).
>
> The nostril (or nose) of the elephant is long and strong, and the animal uses it like a hand; for by means of this organ it draws objects toward it, and takes hold of them, and introduces its food into its mouth, whether liquid or dry food, and it is the only living creature that does so (492^b, 17).
>
> Women do not grow hairs on the chin; except that a scanty beard grows on some women after the monthly courses have stopped. . . . Individuals that are destitute even of [hair] upon the pubes are constitutionally impotent (518^a, 34–518^b, 3).

> If a hair be cut, it does not grow at the point of section; but it gets longer by growing upward from below (518^b, 28).

> Web-footed birds without exception live near the sea or rivers or pools, as they naturally resort to places adapted to their structure (615^a, 24).

This last statement is so characteristic of Aristotle—always seeking relationships. Instead of saying only that ducks, gulls, etc. have webbed feet, he relates this natural phenomenon with another natural phenomenon—the habitat of birds with webbed feet. And that is what science is all about: seeking explanations by relating one phenomenon to other phenomena.

Aristotle notes that apes are intermediate between human beings and the other quadrupeds:

> Some animals share the properties of man and the quadrupeds, as the ape, the monkey, and the baboon. The monkey is a tailed ape. The baboon resembles the ape in form, only that it is bigger and stronger, more like a dog in face, and is more savage in its habits, and its teeth are more dog-like and more powerful.

> Apes are hairy on the back in keeping with their quadrupedal nature, and [have scant hair] on the belly in keeping with their human form. . . . [The] face resembles that of man in many respects; in other words, it has similar nostrils and ears, and teeth like those of man, both front teeth and molars. Further, whereas quadrupeds in general are not furnished with lashes on one of the two eyelids, this creature has them on both. . . .

> The ape has also in its chest two teats upon poorly developed breasts. It has also arms like man, only covered with hair, and it bends these legs like man, with the convexities of both limbs facing one another. In addition it has hands and fingers and nails like man, only that all these parts are somewhat more beast-like in appearance. Its feet are exceptional in kind. That is, they are large hands, and the toes are like fingers, with the middle one the longest of all. . . . The creature uses its feet either as hands or feet, and doubles them up as one doubles a fist. . . . It has neither hips, inasmuch as it is a quadruped, nor yet a tail, inasmuch as it is a biped. . . . The genitals of the female resemble those of the female in the human species; those of the male are more like those of a dog than are those of a man (502^a, 17–502^b, 24).

One must not read between these lines and claim that Aristotle is a Darwinian evolutionist. Nevertheless he is emphasizing a natural phenomenon, the resemblance of human beings and the other primates, that was to puzzle naturalists until Darwin offered his explanatory hypothesis.

But Aristotle was not always correct; for example, "The lion has its neck composed of a single bone instead of vertebrae" (497^b, 16) and "Males have more teeth than females" (501^b, 20). He also believed that the heart, not the brain, was the seat of consciousness and intelligence.

Nevertheless, *Historia Animalium* is an extraordinary achievement. There was nothing like it before, and none known to me of a later date, that presents in a single small book such a broad sweep of observations and attempts to understand them in naturalistic terms.

Historia Animalium deals mainly with the structure and habits (especially of reproduction) of an estimated 500 different species—both vertebrates and invertebrates. Much of what is said remains correct to this day.

An aside: I suspect that one could present a most stimulating and useful seminar for biology majors by working through *Historia Animalium* with them, page by page, and asking students to evaluate Aristotle's statements: "Do they agree with our current understandings?" or "What could have been the observations that led Aristotle to that conclusion?" For example, how could Aristotle determine that hair grows from the base, not the cut surface?

De Partibus Animalium

Aristotle was less successful in understanding the function of those organs that he was often able to describe in fair detail.

Nevertheless, he made the attempt in *De Partibus Animalium*—"Of The Parts of Animals" or, as Aristotle would have preferred, "Of the Causes of the Parts of Animals." The meaning of that puzzling title will become apparent shortly. As was the case in *Historia Animalium,* Aristotle pays great attention to the significance of the data and seeks understanding, not merely description.

De Partibus begins with remarks that are entirely pertinent to our nation's present concern with educational reform and, for the university level, describes what constitutes an educated person, that is, one who is able to make those informed decisions necessary in a democracy. Aristotle recognizes two levels of competence. One is understanding at the level of a specialist—in this case the scientist. The other is the level of understanding of an educated person who cannot expect to be informed in depth in all fields "noble or humble" but must "be able to judge correctly which parts of an exposition are satisfactory and which are not" (639^a, 5). Thus the broadly educated person must be able to evaluate what is said in all fields and reach a conclusion about its level of acceptability.

Next Aristotle seeks to determine the proper questions to ask about natural phenomena:

> It is clear that in the investigations of the natural sciences there must be agreed upon general rules by which the acceptability of the methods may be tested—independently of whether the statement is true or false. Should we, for example, discuss each species—man, lion, or ox—separately. Or should we first ascertain their common characteristics, there being many attributes which are identical that occur in many different groups of organisms—sleep, respiration, growth, decay, and death. I raise this, for at present there is not an agreed upon scheme. However, this much is plain, if we discuss them species by species we shall be repeating the same descriptions for the many different animals since, for example, every one of the common characteristics mentioned above occurs in horses, dogs, and human beings alike (639^a, 639^b; here and in the following remarks of Aristotle I have paraphrased and condensed the translations of A. L. Peck and William Ogle).

Aristotle's answer is to emphasize the common attributes of different species—the similar ways that they solve the basic problems of life—which is the same approach that has proved so successful in all branches of biology. This approach emphasizes, also, the similarities among organisms in contrast with treating each one as entirely separate from all other species—a point of view that must follow if each species represents a unique act of Divine Creation.

Apart from this emphasis on common attributes rather than uniqueness, Aristotle says there are other choices to be made. One must come to understand the Causes, or reasons for, the phenomenon and to decide whether the Final Cause or the Efficient Cause should be ascertained first.

> Should the student of Nature consider first of all the phenomena which occur in whole animals as well as their parts and then state the reasons and the causes; or should some other procedure be followed? There is the Cause *for the sake of which* the thing is formed, the Final Cause, and there is the Cause of the *beginning of the motion,* the Efficient Cause. Clearly the one that stands first is the one which we call the "Final Cause." It is the reason for which the thing has formed and for which it exists (639^b).

Aristotle recognized two other Causes in addition to the two just mentioned. All four are important in his analysis but difficult for us to understand. Their main importance for us today is that they show how, at the very beginning of the biological sciences, a fine mind attempted to see things more clearly. The Final Cause can be loosely construed, when applied to morphology and physiology, as being the purpose or function of the structure or process. The Final Cause of the eye is sight. This is Aristotle's dominant concern in *De Partibus.* (For a discussion of the four Causes see SAAWOK—IV, pp. 434–436.) To the extent that the Final Cause is responsible for the phenomenon in question, this is a teleological explanation.

One of the great values of the physiological analyses in *De Partibus* is that they show vividly the enormous difficulties in asking questions when the techniques, basic information, and approaches are inadequate. The human body and the bodies of other organisms were Black Boxes to Aristotle. Food and air go in and solid and liquid wastes come out. The opened body shows a bewildering collection of parts. Tubes and strands connect all the parts. The living organism may be active in the extreme but if its body is opened immediately after death all is quiet. Nothing seems to be happening. Aristotle could see structure but he could not see function—that had to be inferred and, in the 4th century B.C., many of the inferences were wrong or incomplete. Nevertheless Aristotle made an enormous contribution: *he tried to ask the important questions and he sought naturalistic answers.*

As examples of Aristotle's understandings of physiology, the following are what he believed the functions of the organs of the gut, blood, lungs, kidney, and bladder to be. For the most part he is dealing with mammals, including human beings.

He observed that an animal can neither exist nor grow without food. Therefore the two parts most necessary are those that take food in and those that eliminate the residues. The food is not used as such but is changed in the body by heat. The source of this heat is the heart. When the food needs to be broken up, this is done in the mouth by teeth. When the food is in small pieces it is easier for the heat to act upon it. The food then passes to the stomach and intestines. The food is transformed and then enters the blood vessels of the mesenteries attached to the stomach and intestines and is distributed to the parts of the body. The liver is a necessary organ for the use of the food in blood. In fact, the final form of food is blood.

> These and similar considerations make it clear that the purpose of the blood in living creatures is to provide them with nourishment . . . that is to say, nourishment for the parts of the body (650^b, 5, 15).

I suspect that Aristotle's understanding of the requirements for food, and how the parts of the body receive it, is as good as that of the average person living today in the United States.

Aristotle is less successful in understanding the function of breathing. The lung is present for the sake of breathing. The main function of breathing is to cool the body, which we know is one of its functions. It must have been obvious to the ancients that the human body produces heat, especially in disease with fever. It was true, also, that one feels "hot" after strenuous exercise and notes the increased rate of breathing.

He does understand the basis of inspiration and expiration:

> When the lung rises up, the breath rushes in, and when it contracts the breath goes out again (669^a, 18).

Aristotle said that the purpose of the kidneys and bladder is to deal with residues. He notes an interesting relation between blood vessels and the kidney and he has an astonishing insight into kidney function.

> The duct that extends from the great blood vessel to the kidneys does not terminate in the cavity of the kidneys but the blood is spent on the body of the kidneys. Thus no blood enters the cavity of the kidneys and none congeals there after death. Other channels come from the aorta to the kidneys; these are strong, continuous ones. This arrangement is for the purpose of enabling the residue to pass out of the blood-vessel into the kidneys, and so that, when the fluid percolates through the body of the kidneys, the excretion that results may collect in the middle of the kidneys, where the cavity is in most cases. From the cavity of the kidneys two sturdy channels [the ureters] lead to the bladder, one from each kidney. These contain no blood (671^b).

This account of kidney physiology just about takes us to the 19th century.

These short excerpts will give something of the flavor of *De Partibus,* the first textbook of animal physiology—moreover one emphasizing comparative physiology.

THE CLASSIFICATION OF ANIMALS

Aristotle recognized clearly that there were biological similarities among animals. Some were so alike that they were the same kind, which he called species as we do today. The different species seemed to fall into groups. The fewer the species in a group, the more natural it was. For example, there were greater resemblances among all viviparous quadruped species than among all species with blood.

Aristotle did not attempt to provide a rigid hierarachical system of classification that would encompass all animals. Nevertheless, in his goal of seeking resemblances among organisms instead of dealing with them one by one, he found it useful to recognize some major groups.

His two basic groups were those with blood and those without. The former group is nearly identical with "vertebrates" and the latter with "invertebrates." Among those with blood, the vertebrates, the major subgroups were:

> man; viviparous quadrupeds (mammals); birds; oviparous quadrupeds, including some similar in most ways but lacking feet (reptiles and amphibians; and fishes).

Among the bloodless animals the main groups were:

> soft and shelled animals (crustaceans); the "softies" (cephalopods); insects; shelled animals (mollusks and echinoderms plus the sea anemones and sponges).

In addition to these main groups, Aristotle mentions that there were others that had not been named. He failed to name them, the cardinal sin for many taxonomists who came later.

Of particular interest is Aristotle's extreme caution in classifying animals. He implies that others had used single character differences and that often this resulted in artificial groupings, which suggests that Aristotle had an intuitive grasp of what we mean today by a "natural" group. For example, he records that some naturalists had divided animals as those living on land and those living in water. That dichotomous scheme would place some mammals (whales, etc.), some birds, and fishes in one group and other mammals, birds, and the reptiles in the other group. And as noted a few paragraphs back, he included some species, snakes for example, in the oviparous *quadrupeds.* These creatures, far from having four legs, have none at all. Nevertheless, he felt that they resembled lizards, etc., in so many other ways that they should be placed, naturally, in the same class.

> The proper course is to endeavor to place the animals according to the groupings used by people in general who recognize the group "birds" and the group "fishes." Each of these groups is marked by *many differences,* not by means of dichotomy. . . . Yet some find it puzzling that general usage has not combined the water-animals and the feathered animals into one higher group and adopted one name to include both, seeing that in fact these two groups have certain features in common [oviparous, for example]. The answer is that, in spite of this, the present grouping is the right one. The reason is that groups that differ only "by excess," that is, one bird's feathers are long, another's short, are placed in the same group. Those which differ so much that their characteristics are only analogous are placed in separate groups. Thus between a bird and a fish the correspondence is only by analogy—a fish has no feathers at all, but scales, which are analogous with them (643^b, 644^a).

Aristotle's main contribution to classification was to maintain that there are natural groups—based on structure, physiology, mode of reproduction, and behavior—and that a hierarchical organization exists. Of equal importance, I suspect, was his caution. In contrast with many taxonomists who came later, he did not try to fit the species to the system but realized that a system must deal with natural affinities.

THE ARISTOTELIAN SYSTEM

Who was Aristotle? There is no doubt there was such a person but we are less sure of the relation of *Historia Animalium, De Partibus Animalium,* and *De Generatione Animalium,* to that specific 4th century B.C. individual. See, for example, the Introduction to Hett's translation of Aristotle's *On the Soul* (1957).

Those three classics form only about a quarter of his works in all fields of science and philosophy. How could any one individual have done so much? One answer is that the works of "Aristotle," while stimulated and produced in the main by the real Aristotle, include also the observations and writings of his students and of naturalists who lived at a later time. There is some evidence that there were substantial editorial changes for at least 250 years after his death. The Aristotelian corpus was hand-written; there was no other choice, and the possibility of error, additions, and deletions with each new copying was substantial. The oldest extant manuscript dates to the 9th century A.D.—more than a thousand years after Aristotle's death.

All this is of little concern for us. The major point is that someone in the Athens of the 4th century B.C. set the course for the science of biology. Let's call that someone "Aristotle" as it most probably was. Alfred North Whitehead said that all of Western philosophy is a footnote to Plato. It is not hyperbole for us to say that all of biology is a footnote to Aristotle. He defined the field, outlined the major problems, and accumulated data to provide answers—he set the course.

His major contribution was to isolate natural phenomena from external forces. He sought answers not in the gods, demons, spirits, and forces of the supernatural world that characterized the thought patterns of more ancient civilizations but in nature itself. The cause is natural, not supernatural. Knowledge of natural phenomena comes from the application of disciplined thought to data acquired by observation.

His view that what an animal is and does resides primarily within the animal remains a first principle of biology:

> The germ that gives rise to the animal must at the very beginning have the appropriate specific character (*De Partibus,* 640^{a}, 24).

He was forever seeking relations among phenomena—birds with webbed feet are aquatic. Explanation in science is primarily a matter of relating different sorts of phenomena.

Aristotle parted also from his teacher, Plato, who sought reality not in the objects of nature but in the ideas underlying them—a reformed supernaturalism. Reason was the source of knowledge, not information provided by the senses. As Ernst Mayr has observed,

> Without questioning the importance of Plato for the history of philosophy, I must say that for biology he was a disaster. His inappropriate concepts influenced biology adversely for centuries. The rise of modern biological thought is, in part, the emancipation from Platonic thinking (1982, p. 87).

It should be noted in passing that Aristotle had far less success when dealing with astronomy and the physical sciences than with biology. With them he proceeded, as did Plato, to fit the facts of nature to a preconceived theory of the causes of natural phenomena. This is deductive science, which can be successful only if the basic theory is correct. In Aristotle's case the theory was not correct and his elaborate description of physical nature was eventually demolished, two millennia later, by Galileo and others. Aristotle's biology was largely inductive and, for that reason, proved far more successful.

Many of the novel ways Aristotle looked upon nature have become so much a part of our thought patterns that they are taken for granted. One was that structures have functions. In fact, he seems to have separated structure and function less than is done today. When he reports on structure it is nearly always as a prelude to speculations about modes of action and broader significances. Structure was regarded as basic to what was really important—function. Thus how the body obtains the food necessary for maintenance and growth is the more important phenomenon, not the detailed anatomy of the structures involved. It seems unlikely that in Aristotle's time the Lyceum had separate courses in Comparative Anatomy and Comparative Physiology.

Since he was interested mainly in the process rather than the thing, he took the comparative approach that remains valuable to this day. The basic functions of living creatures—obtaining food, reproduction, behavior, development—are better understood if observations are made on a variety of organisms.

Although too cautious to propose a rigorous scheme of classification he laid the groundwork for one and discussed some of the difficulties. The basic characteristic of biological classification is its hierarchical structure and Aristotle was fully aware that organisms could be arranged in groups of different degrees of inclusiveness. He warned also of the danger of artificial, dichotomous classifications, those based on single character differences, that would divide natural groups. To him natural groups should be defined as those possessing many characteristics in common.

He realized that there were two types of resemblances that we now call homology and analogy and that they are fundamentally different.

The notion of a *Scala Naturae,* or the arrangement of all animals in a linear series based on increasing complexity—to become so important in later centuries—began with Aristotle. One example was given before—that man, apes, and the other quadrupeds with hair formed a sequence. He noted, incorrectly to be sure, that seals and cetaceans linked to some degree the marine animals, such as fishes, with terrestrial animals with blood. It seemed to him, also, that in some ways the bats linked birds and mammals. He even suggested that there were links between animals and plants: sponges, tunicates, and coelenterates, for example. These animals may have superficial resemblances to plants.

Here as elsewhere, Aristotle recognized a problem but did not offer a satisfactory solution. The business of biology is the solution of problems but, for that to be done, the problem has to be recognized—hence his important contribution.

Aristotle has been much berated for his teleology, a cardinal sin for those in our generation. Nevertheless he was dealing with a basic phenomenon, that is, the relation of structure and function to the animal's way of life—the extraordinary adaptations that have astonished naturalists in all ages. The purpose of wings is flight, which is rather obvious. The problem arises when the teleologist implies that, somehow, *purpose* is the guiding force in the formation of wings.

If one accepts that the purpose of wings is to enable the organism to fly, there are two main ways of accounting for them:

1. Wings are the consequence of a series of developmental events, explainable or not, that have resulted in wings.
2. There is a transcendental "wing-forming force" that molds the formation of wings.

I do not believe that Aristotle meant the latter. Surely he must have realized that the stimulus for the development of wing buds in the chick embryo could not be the still to be formed wings (see Mayr, 1982, pp. 47–51 for a discussion of how the term "teleology" is used). In any event, he was providing data of a sort that would find their explanation in the concept of Darwinian evolution.

Aristotle's realization that composite parts are composed of simple parts, and that the same building blocks can be assembled to produce quite different structures, are concepts that remain useful to this day. Furthermore, function itself is closely associated with composite parts, that is, organs.

He said little about experimentation, which was to prove such a powerful tool for answering questions. In fact, the large-scale use of experimentation to test deductions was not to begin until the days of Galileo in the late 16th and early 17th centuries. Nevertheless, Aristotle may have employed it to some degree. How else could he have said that hair grows from the base, not the cut surface? The observation of sexual impotence in castrated animals is surely based on an experiment, even though the experiment was probably undertaken for non-scientific reasons. In addition, he takes advantage of some natural experiments: hair may begin to grow on a woman's chin once the menopause has passed.

It was this lack of systematic use of experimentation that produced Aristotle's defective physics. It cannot be maintained that experiments in physics would have been impossible for Aristotle. He held, for example, the commonsense notion that light objects, such as paper or feathers, fall more slowly than heavy ones. That notion was held, of course, because of observations that a piece of paper floats gently to the ground in contrast to the rapid descent of a rock. This result can be explained as due either to the relative masses of the two objects or to their shapes. Had Aristotle experimented, he might have crumpled a piece of paper into a tight wad and compared its rate of descent to that of a sheet. If he had done that, the science of physics would have had a very different history.

A basic component of Aristotle's view of nature was his notion of the existence of a phenomenon described by a word generally translated as "soul." The word has also been translated as "living force," "life," or "vital principle." It has little, if any, relation to the Judeo-Christian meaning of soul. No doubt the idea arose as an explanation of the difference between an animal alive and then killed. The form remains the same before and after but there is some basic, though mysterious, difference. In fact, it is the soul that gives "form" to the "matter" of living creatures and it exists only in relation to them. Whatever it is, Aristotle realized that it is restricted to what is alive and that its form varies with the complexity of the organism.

Plants have the lowest level of "souls," theirs being concerned only with nutrition and reproduction.

Animals differ from plants in having sense organs and a sentient soul along with the nutritive and reproductive soul as in plants. Human beings add a still higher level, the rational soul.

Aristotle believed that the soul is something apart from the basic elements—fire, earth, water, and air—possibly including a fifth element, *pneuma*. Aristotle was recognizing a phenomenon—the living state—and trying to provide ways for the rational soul to deal with it. This was not a very useful advance. Hypotheses in science are most productive when they associate different phenomena in testable ways. Aristotle's hierarchy of souls does no more than give names to some of the different things that living creatures do. The explanation that animals have sense organs that allow them to sense the environment because they have a sentient soul really does not advance the argument.

Although Aristotle did not begin the study of animals, his is the oldest extant comprehensive treatment of what we now call biology. He undertook this study *because he found it interesting to do so.* He was seeking knowledge for the sake of knowledge—there was no useful goal in this quest. Edith Hamilton (1942) paraphrases a portion of *De Partibus* as follows:

> The glory, doubtless, of the heavenly bodies fills us with more delight than the contemplation of these lowly things, but the heavens are high and far off, and the knowledge of celestial things that our senses give us, is scanty and dim. Living creatures, on the contrary, are at our door, and if we so desire we may gain full and certain knowledge of each and all. We take pleasure in a statue's beauty; should not then the living fill us with delight? And all the more if in the spirit of the love of knowledge we search for causes and bring to light evidences of meaning. Then will nature's purpose and her deep-seated laws be revealed in all things, all tending in her multitudinous work to one form or another of the beautiful.

REFERENCES TO ARISTOTLE

The literature is simply enormous and no attempt is here made to be comprehensive. Other aspects of Aristotle's biology are considered in SAAWOK—III, pp. 589–591 and SAAWOK—IV, pp. 420–426, together with appropriate references. The following works will allow those interested to enter the literature.

Aristotle (his works listed in "References"), Cole (1975), Downey (1962), Farrington (1949), Grene (1963), Jaeger (1948), Lloyd (1968), Lones (1912), Magner (1979), *Mayr (1982), Owen *et al.* (1970), Pellegrin (1986), Preus (1975), Randall (1960), Ross (1949), *Russell (1917), Sarton (1927–1948, 1952), Singer (1922*a*, *b*, 1950), Thompson (1922), and Woodbridge (1965).

FORM AND FUNCTION—THE BASIC QUESTIONS

In his biological investigations, Aristotle sought to describe in a systematic manner the structure of as many organisms as he could, ascertain the functions of those structures, discover the patterns of reproduction and development, and learn about behavior. That is all descriptive biology, which was only the beginning of the analysis for Aristotle. He appeared to have been far more interested in understanding the "hows" and "whys" of the observed phenomena. He considered what were to remain the most general questions that could be asked about the animal way of life. They were:

1. What is the nature of the *vital principle*? That is, what is responsible for giving matter the ability to exhibit the characteristics of living creatures. All begin as a seed or egg and undergo a differentiation, grow, reproduce at maturity, and die. In contrast with the non-living world, where objects do not seem to change, life is characterized by constant change.

2. How can this vital principle, so much the same in all living creatures—jellyfish, ferns, elephants, birds, trees, and human beings—be expressed in creatures so different in form and function? *Is "being alive" basically the same for all creatures?*

3. What is required for the *maintenance* of life?

4. What is responsible for the *diversity* of living creatures—both the variation of the individuals of a species as well as the differences among species?

5. What can account for the similarities among organisms and hence the possibility of recognizing *natural groups*? How can there be *hierarchies* of natural groups?

6. What is responsible for *like producing like* or, as we would now say, genetic continuity? That is, what insures that offspring resemble their parents?

It is important to note, once again, that the answers to these questions were of no practical importance. No one in ancient Greece would have benefited economically or politically by knowing the answers. The questions were asked and answers sought by a very few individuals who could afford the luxury of speculation because of the intellectual joy that came with understanding.

But such individuals are rare and Aristotle's two-pronged approach—collecting data and speculating about it—was not done systematically by those who followed him. His successors engaged, for the most part, in what Kuhn (1970) refers to as "normal science," that is, filling in the details of the explanatory paradigm accepted by the majority of scientists at a given time.

If the documents that have survived are any indication, the main interest among Aristotle's followers was the biology of human beings and this meant studying the structure of the human body and trying to determine the function of its parts. Progress was measured by centuries but there was one notable exception.

THEOPHRASTUS

Although Theophrastus was younger than Aristotle both were students of Plato and were together in Aristotle's school in Athens—the Peripatetics. He was born in 371 B.C. on the island of Lesbos, where Aristotle lived for a while, but most of his life was spent in Athens. After the death of Aristotle, Theophrastus became the master of the school. He died in 287 B.C.

Theophrastus was a person of broad learning but he is known to us almost exclusively as a botanist—his other works have not survived. In his *Inquiry into Plants* he attempts to do for botany what Aristotle did for animals in *Historia Animalium.* Nothing so important had been done before so Theophrastus can be acclaimed as the Father of Botany.

Theophrastus began his *Inquiry* by noting both the special features of plants and the extent to which they resemble animals. Plant development is far easier to study than animal development. He described the germination of many kinds of seeds, noting for example, the origin of root and stem and their relation of the origin to the point of attachment of the seed to either the pod or stalk. In the cereals the root starts from the broader, lower part of the seed and the stem from the opposite end. Nevertheless, the root and stem are continuous. The legumes, on the other hand, produce root and stem from the same point on the seed, namely where it had been attached to the pod (*Inquiry*, VIII, ii, 1–2).

Theophrastus had difficulty in dealing with the structures of plants. This was a consequence of the ephemeral nature of some of the plant parts. Animals do not lose their parts—arms, eyes, or stomachs. Plants do: leaves of many trees are lost in the autumn; fruits form and fall. He decided that the more important parts are roots, stems, branches, and twigs. These are more permanent and correspond in their importance to the parts of animals. The roots enable the plant to draw nourishment from the soil.

He recognized sap, fibers and veins. Not being aware of any names for those parts of plants, he decided to use the names of structures that occur in animals. His reasoning for so doing is most interesting, with applicability far beyond this particular need.

> It is by the help of the better known that we must pursue the unknown because the better known are things which are larger and plainer to our senses (I, ii, 4).

Here is a mind seeking relationships and common principles.

He attempted to classify plants and the categories he chose were trees, shrubs, undershrubs, and herbs. Theophrastus could not make these categories discrete and noted much overlap. Clearly he was not satisfied with his classification. He did have a good understanding of the differences that centuries later were to form the basis of a more acceptable classification: angiosperms and gymnosperms; monocots and dicots; the parts of flowers; and hypogynous, epigynous, and perigynous arrangements of flower parts.

The *Inquiry into Plants* is an extensive monograph. More than 500 species are described and there is much information about domesticated varieties. As was the case with Aristotle's *Historia Animalium*, much of the information is based on what Theophrastus read or was told by others. He recorded that different parts of the then known world may have different species and that climate is important in plant growth. He knew the importance of dung as a fertilizer and recognized many species of plant pests. He provided considerable information about timber trees and which kinds are best suited for building houses, ships, furniture, or for making charcoal.

Aristotle and Theophrastus approached nature inductively and built a body of biological information on the basis of observations. The data so obtained were used to develop explanatory hypotheses. Their approach was to prove highly productive in later centuries with the addition of another procedure—the experimental testing of hypotheses. Their accomplishments were so noteworthy, and recognized as such at the time, that one might have hoped that their rational approach would be accepted by all.

Not so. Two millennia were to pass before biology achieved the operational level of Aristotle and Theophrastus. Seemingly the Second Law of Thermodynamics works for intellectual pursuits as it does for physical processes. After Aristotle and Theophrastus there was a notable increase in entropy in the biological sciences. Two examples of conceptual entropy will be noted, Pliny and Aelian.

PLINY

Gaius Plinius Secundus, a noble Roman, was born in 23 A.D. and died in the eruption of Vesuvius on 25 August 79 that buried a wide area near Naples, including Pompeii and Herculaneum.

Pliny was a man of great accomplishment. He served in the army, and at the time of his death was commander of the Roman fleet based in the Bay of Naples. He also had held various governmental posts. He is important for us because of his *Historia Naturalis,* an encyclopedic work covering the physical universe, geography, anthropology, biology, mineralogy, medicinal plants, and the fine arts. That is a broad survey and in his dedication of the work to the Emperor Titus he says that no other person had made a similar attempt.

Books VII through XIX treat human beings, other animals, and plants. Nearly all of Pliny's information was derived from the literature. He claims to have checked 2,000 volumes by 100 authors and extracted 20,000 facts. He was either overly modest or poor at addition as Eichholz (1975) counts 473 authors and 34,707 facts. His *Historia Naturalis* is a valuable compilation of information from a wide variety of Greek and Roman works, some of which have not survived. Later authors have often criticized Pliny for his gullibility and lack of originality. The second criticism is strange indeed—one does not expect new discoveries to be first announced in an encyclopedia. The flavor of what he had to say is given by the following:

The world is to be regarded as a deity and eternal, with no evidence of a beginning or an end. Matter is composed of four elements: fire, air, earth, and water. There are seven planets among the many stars. The sun rules the seasons and the stars. It is to be regarded as the supreme ruling principle and divinity of nature, a point of view that was held by Homer. The facts reported about the movements of the planets, stars, and sun are astonishing. He knew that the position of the sun coincides with the center of the earth (the equator) at the equinoxes and with the Tropics of Cancer and Capricorn at the solstices. The sky belongs to the main god as the earth belongs to human beings. The earth is kind, gentle, and indulgent and lavishes us with her bounty—yet we abuse her in so many ways.

He discusses the mighty battle between the scholars and the common herd about the shape of the earth. The scholars maintain it is a sphere and that there are human beings everywhere. Thus the feet of those on opposite sides point to each other (hence, the "Antipodes"). The herders would expect those people on the other side to fall off but Pliny points out that those on the other side would have the same worries about us, yet we seem to have no problem holding on. He writes that there are many reasons for believing the earth to be a sphere—one is that when a ship puts out to sea the top of the mast is the last part to disappear. The sea surrounds the earth and it does not fall off because the pressure for convergence toward the center prevents that happening.

There are five main climatic zones: two regions crushed by cruel frost and everlasting cold at the poles; two temperate zones, and a torrid zone. The torrid zone is so hot that the temperate zones are effectively isolated from one another.

The tides are related to the moon and are extreme when the sun and moon are opposite one another (full moon) and when they are together (new moon).

A marsh at Samosata produces an inflammable mud—petroleum. Water makes it burn more fiercely but it can be put out by covering it with soil.

The east–west portion of the earth known to Pliny, India to the Pillars of Hercules (Straits of Gibraltar), was estimated to be a distance of either 8,568 or 9,818 miles. The earth's circumference was determined by Eratosthenes to be 252,000 stadia. (A Greek stadium was equal to 606.75 feet or 0.11 miles; thus the circumference of the earth would be 27,720 miles—not bad, considering that his odometer for the small arc of the earth measured was a pacing camel.)

The most remote place to the northwest known to Pliny was Thule (possibly northwest Norway), where at midsummer there was no night and at midwinter no day. One day's sail away is a frozen sea. As Pliny discussed areas ever more remote from the Mediterranean, the information tended to become fantastic. He suggested why this might be and gave this example. In a campaign in northwest Africa the Roman legions pursued the defeated natives as far as Mount Atlas. The legions were led by ex-consuls and generals drawn from the Senate so one might have hoped for accurate reports. No so

> because persons of high position, although not inclined to search for the truth, are ashamed of ignorance and consequently are not reluctant to tell falsehoods, as credulity is never more easily let down than when a false statement is attested by an authority of weight (V, i, 12).

But Pliny told all, so there are mixtures of fact and fable when he discussed the remoter parts of the earth.

In Book VII, Pliny began his zoology with a discussion of human beings. Man is the highest species of animal and the others have been created by nature for him. He alone is born naked—all other creatures have feathers, fur, spines, or bark. Only man experiences grief, weeps, or knows luxury. He alone has ambition, avarice, undue appetite for life, superstition, or worries about what happens when he dies. Other species stand together, whereas man alone is most evil to his own kind.

In those far off places, there are some truly strange human beings: some eat human flesh, may have a single eye in the middle of the forehead, fight with griffins, have their feet turned backward, see better at night than during the day, cure snake bites by mere touch, have poisons in their bodies that kill snakes, serve as both males or females (the Androgyni), bewitch at a glance, have double pupils, stand looking at the sun all day, have eight toes on each foot, have only one leg and move by jumping, have no necks but eyes on the shoulders, and so on.

And there were giants. An earthquake in Crete exposed the bones of a body 69 feet high. It was assumed to be the remains of a god. (Such reports were surely based on observations. The fossils of very large marine and terrestrial species have been noticed since ancient times but their significance was not known.)

Pliny gave a superficial and none too accurate account of human reproduction, remarking that if the mother has too much salt in her diet the children are born without nails, and that a sneeze following copulation is likely to cause an abortion. Male babies who are born feet first almost never have successful careers. Marcus Agrippa was so born and although he reached high station he paid the penalty for feet-firstness when his daughters bore sons who were to grow up to become those most terrible of emperors, Caligula and Nero.

His remarks on heredity show the confusion that was to last to the 20th century. Sound parents could have normal or deformed children, and the same was true for abnormal parents. Specific traits may be inherited for several generations. A woman with white skin bore the daughter of an Ethiopian. The daughter was white but bore a son who was black like his grandfather.

Some human beings are exceptionally strong, fleet of foot, have exceptional eyesight or exceptional character. Julius Caesar could dictate four letters at the same time; he could write and read or dictate or listen at the same time. He fought 50 battles, and was responsible for the death 1,192,000 human beings.

Near the end of his natural history of human beings, Pliny explored the question of an after-life. The soul and its various attributes

> are fictions of childish absurdity, and belong to an existence greedy for everlasting life. So also is the vanity of preserving men's bodies. . . . What is this mad idea that life is renewed by death? What rest will the generations have if the soul retains permanent sensation in the upper world and the ghost in the lower? Most surely this sweet but improbable fancy destroys nature's chief blessing—death—and doubles the sorrow of one about to die by the thought of sorrow to come hereafter also. For if it is sweet to live, who can find it sweet to have done with life? (VII, lv, 189, 190)

Pliny then went on to discuss animals living on land beginning with the largest, and next to human beings the most intelligent—elephants. Their virtues include honesty, wisdom, justice, and reverence for the sun and moon. They also understand the obligations of the religions of people. Pliny described their habits, which include a great deal of improbable or erroneous folklore. Their use as domestic animals, their fights with men and wild animals in the Circus, and their service in war are described. They are humiliated if they lose their place of honor, as in a parade, and are shamed if conquered. Being modest they mate only in secret, and adultery is unknown. They may fall in love with human beings. They are naturally gentle, and when captured are quickly tamed with barley juice. They are terrified by the squeal of pigs, and are liable to flatulence and diarrhea. They eat with the mouth but drink and breathe with an organ that can be called a hand. They hate mice. Their ivory tusks are in great demand. The epicure finds delight in the skin of the trunk, which Pliny explained is a case of the epicure thinking that he is munching ivory. Elephants and pythons are natural enemies and fight to the death. The python circles the elephant and the dying elephant falls and crushes the python. The python can attach itself in the elephant's ear (which cannot be reached by the trunk) and drain the elephant of blood.

Accounts in the literature available to Pliny suggested that snakes could be remarkable. Some in India are of such size that they can swallow whole stags and bulls. Others can catch birds flying fast and high above them. A Roman general, using catapults, killed one 120 feet long, and brought the skin and jaw bones back to Rome and placed them in a temple for all to see.

The last portion on zoology, in Book XI, considers more general matters. He accepted spontaneous generation: the larvae of flies are generated out of dirt by the rays of the sun. There is some attempt at correlation: animals with blood have a head; creatures that possess only the sense of touch (sponges, and some shelled animals) have no head.

There are descriptions of the internal organs of human beings and some of other vertebrates. There is the clear implication that the organs of different species correspond to one another. Much of the data concern structure and little is said about function.

The heart is believed to be the first organ formed when the embryo is in the womb. It has a definite movement, almost as though it were an organism within an organism. It is protected by the ribs and is the source of the vital principle and of the mind. Two large veins extend from it—carrying blood to all parts of the body. When the heart is wounded, the animal dies. The heart was inspected by augurs who then foretold the future by its condition. Julius Caesar had a person sacrificed on the first day he became dictator and that person was found not to have a heart. This was obviously a bad omen for the sacrificed person but also for Caesar—as events were soon to show.

Pliny summarized the literature reports on many mammals, other vertebrates and some invertebrates. Seemingly he accepted all because,

> When I have observed Nature she has always convinced me to believe that no statement about her is incredible (XII, ii, 6).

As a consequence, much of what he recorded is incredible. Nevertheless, his *Natural History* is tremendously important because it is a compilation of what was generally believed. If a modern-day Pliny attempted to include everything written in the last few centuries about animals, the product would bear a discouraging resemblance to the Pliny's *Natural History* of the 1st century A.D.

Pliny's interest in natural history continued to the very end of his life and the manner in which that end occurred suggests that he was not gifted with the ability to evaluate data relating to natural phenomena.

As mentioned before, Pliny was serving as commander of the Roman fleet stationed at the Bay of Naples when, early on the morning of 25 August 79 A.D., he was told of an unusual cloud hanging over Mt. Vesuvius. Prior to this there had been numerous earthquakes. After sunning himself, taking a cold bath, and having a light breakfast, Pliny climbed a hill for a better view of the strange event. A huge cloud, resembling a pine tree, hovered over the mountain.

He decided to go closer and obtain more information. He was about to sail across the bay in a small vessel when an urgent message came from a friend, telling that the inhabitants near the mountain were in great danger and needed to be rescued. Escape over land appear to be impossible. He changed his plans and decided to be rowed in the four-ranked galleys, which would be large enough to evacuate many people. Thus, as his nephew Pliny the Younger wrote (J. D. Lewis, 1879, p. 192): "Having started on his enterprise as a student, [he] proceeded to carry it out as a hero." (Pliny the Younger stayed home to do some studying and so lived to tell this tale in two letters—Book VI, 16 and 20—to the Emperor Tacitus. Even he had a narrow escape, as the volcanic debris was distributed over many miles.)

The closer Pliny's galleys came to the shore, the greater the amount of ash, pumice, and stones that rained upon them. He dictated his observations, including the fact that there had been a sudden retreat of the sea and the blotting out of the sun by the volcanic clouds. A landing had to be made some distance from the mountain but Pliny found his friend. In the hope of calming the people, he went to the baths and then sat down for a meal. Afterwards he took a nap, including snoring.

During all this time Vesuvius was sending up sheets of flame and clouds of debris. In fact, the level of the ash in the courtyard was becoming so thick that shortly it would not have been possible to open the doors. It was decided to awaken Pliny and to discuss what should be done—stay in the house and be protected from the falling debris or attempt an escape and risk being killed by the falling stones. It was decided to try to reach the shore and the ships, since there was evidence that the weight of materials on the roof might cause the house to collapse. So the people put pillows on their heads and made a run for it. Although still day, it was pitch black and torches had to be used. They made the shore and Pliny sat down to rest but was overcome by a sulfurous cloud. His body was recovered after the eruption ended and the sulfurous cloud had dissipated.

This is strange behavior for one who was able to present 34,707 facts about natural phenomena. However, I can not find that Pliny's *Natural History* contains information about volcanic eruptions. He knew about earthquakes (II, lxxxi–xcv) but little about volcanoes. He does refer to "two mountains crashing together and then flames and smoke rising between them" and places where noxious fumes escape from the earth, killing birds and other animals—but not human beings. Furthermore, there was no record of an eruption of Vesuvius in historic times (there have been many since 79 A.D.). Thus, Pliny misjudged the dangers from Vesuvius and, in an effort to reassure his friends, met his death. But remember his statement—death is nature's chief blessing.

AELIAN

Aelian was also a Roman citizen, born 170 A.D. in Palestrina in central Italy. He died about 235. Aelian's chief surviving work is *De Natura Animalium.* His translator, A. F. Scholfield, provides this evaluation:

> The *De natura animalium* is a miscellany of facts, genuine or supposed, gleaned by Aelian from earlier and contemporary Greek writers (no Latin writer is once named) and to a limited extent from his own observations to illustrate the habits of the animal world. . . . Mythology, mariners' yarns, vulgar superstitions, the ascertained facts of nature—all serve to adorn a tale and, on occasion, to point a moral. . . . The wisdom and beneficence of Nature are held up to veneration; the folly and selfishness of man are contrasted with the untaught virtues of the animal world. Some animals, to be sure, have their failings, but he chooses rather to dwell upon their good qualities, devotion, courage, self-sacrifice, gratitude. Again, animals are guided by Reason, and from them we

may learn contentment, control of the passions, and calm in the face of death (pp. xiii–xiv).

The following few excerpts will give the flavor of Aelian's work (paraphrased from Scholfield's translation). This is the opening:

> The island of Diomedea is the home of many shearwaters, which neither harm the barbarians or go near them. However if a stranger from Greece puts into port, the birds by some divine dispensation approach and extend their wings to embrace the strangers. If the Greeks stroke them, they do not fly away and if the men sit down the birds fly into their laps as though they had been invited to a meal. The birds are said to be the companions of Diomedes [King of Argos] and to have taken part with him in the [Trojan] war against Ilium. Although the companions were changed to birds, they nevertheless still preserve their Greek nature and their love of Greece (Book I, 1). [Today we use *Diomedéa* as the genus name for the albatross.]

> It seems that the fat of an elephant is a remedy against the poisons of all savage creatures. If a man rubs some of this fat on his body, should he encounter the very fiercest creatures, even when unarmed, he will escape unharmed (I, 37).

> A groom fell in love with a young mare, as he might have with a beautiful girl. After restraining himself for a period, he finally dared to consummate this strange union. The mare had a fine foal and when she saw what was happening she was most upset. She leaped upon the man and killed him. She even went so far as to note the place where the man was buried and proceeded to dig up the corpse and outrage it by inflicting every kind of injury (IV, 8).

Oh, well. This is a far cry from Aristotle who had written five centuries earlier. Aelian probably knew of him only second or third hand. In any event biological science became dormant. We will encounter the uncritical, moralistic style of *De Natura Animalium* once again in the bestiaries of later centuries.

Before we enter the Dark Ages, something must be said about developments in the medical sciences that paralleled Aristotelian and later biology.

HIPPOCRATES

Although the purely biological problems that interested Aristotle were of little obvious usefulness, another branch of biology has always been cherished for its benefit to human beings. This is the biology of the human body, knowledge of which is essential for dealing with health and disease. For the Greeks the recorded history of medicine extends from Hippocrates (*ca.* 460 to *ca.* 375 B.C.) to Galen (*ca.* 130 to *ca.* 200 A.D.)—a span of nearly six centuries. But there was medicine before that. The skill of Egyptian physicians was well known in the Greek world. And Greek medicine remained viable long after 200 A.D. because Galen was to remain *the* authority on human anatomy and physiology until the 17th century.

Hippocrates was born on the Aegean island of Cos to a family of physicians. His name is used to refer to a large body of medical writings, the "Hippocratic Corpus" that includes not only some works by Hippocrates but also those of other physicians of the late 5th and early 4th centuries B.C. To avoid circumlocution all will be credited to Hippocrates. He died about a half-century before Aristotle was born.

Hippocrates revolutionized medical science and he did so in the typical Ionian Greek mode—explaining what he could in a rational scientific manner, suggesting naturalistic hypotheses for what could not be accounted for, and avoiding using supernatural forces in his explanations.

> The scientific nature of Hippocrates' genius appears in his careful observations, moderate judgements, love of truth, and also indirectly, in his rejection of superstitions, irrelevant philosophy, and rhetoric (Sarton, 1952, p. 344).

De Morbo Sacro contains a famous statement of Hippocrates about epilepsy, "The Sacred Disease." It shows how he thought.

> I am about to discuss the disease called "sacred." It is not, in my opinion, any more divine or more sacred than other diseases, but has a natural cause. Its supposed divine origin is due to man's inexperience and to their wonder at its peculiar character. . . . But if it is to be considered divine just because it is wonderful, there will be not one but many sacred diseases, which are no less wonderful and portentous—yet nobody considers them sacred. For example, quotidian, tertian, and quartan fevers [forms of malaria] seem to me no less sacred and god-sent than the "sacred disease." Nobody wonders at them. . . . My own view is that those who first attributed a sacred character to this malady were like the magicians, purifiers, charlatans, and quacks of our own day. These all claim great piety and superior knowledge but, being at a loss to understand and having no treatment that would help, hide behind superstition and, so, do not reveal their utter ignorance (modified from Sarton, 1952, p. 357).

Central to his treatment of patients was the notion of the healing power of nature—nature could restore the body's physiology to its normal equilibrium state. We have here the core of a concept that was to prove of great importance in physiology. Illness was regarded by Hippocrates, and others long before his time, as due to an imbalance of the four humors: blood, which was made in the liver; phlegm, associated with lungs; yellow bile, associated with the gall bladder; and black bile, associated with the spleen. The four main diseases characterized by an excess of one of the humors were sanguine (blood), phlegmatic (phlegm), choleric (yellow bile), and melancholic (black bile). Thus health was achieved when the four humors returned to their normal equilibrium concentrations. This notion was to find more formal expression in Claude Bernard's concept of the *milieu intérieur* of the 19th century and Walter Cannon's *homeostasis* of the 20th century (see Deyrup-Olsen's discussion of Claude Bernard, pp. 149–154).

An important technique of Hippocrates was to record as carefully as possible the symptoms and courses of diseases. This technique, not to be systematically employed again until the 16th century, forms the basis of modern medical diagnosis and prognosis. Physicians in those ancient times had few drugs or other means of treating diseases effectively. The more successful of them relied on diagnosing the ailment and then, on the basis of experience with previous cases, predicting what would transpire. This understanding was used in moral support of the patient and, then as now, the patient's confidence in the physician was an important element in recovery. This benign approach to illness was especially effective at a time when many of the recognized treatments were dangerous and, as always, most patients got well anyway.

But Hippocrates and other effective physicians did have a program for keeping healthy. It involved a recommended life style—one insuring proper rest, diet, and exercise. Moderation in all things was the key to good health. The Hippocratic physician was far less likely to do harm than were many who came after them, for example, those who bled George Washington to death or those who throughout the 19th century poisoned their patients with toxic chemicals or made them drug addicts.

HEROPHILUS

Two notable physicians who followed Hippocrates were Herophilus and Erasistratus. They spent most of their active years in the famous Egyptian city of Alexandria, founded in 332 B.C. by Alexander the Great (356–323). Alexandria was the capital of the Ptolemies until the Roman annexation in 30 B.C. For several centuries it was a great center of learning, with two royal libraries holding possibly as many as 700,000 scrolls. Its glory faded under Roman rule.

Herophilus was born at Chalcedon, an Ionian settlement near the present-day city of Istanbul. He was active in the last third of the 4th century B.C. His professional life was spent mainly at Alexandria, where he started the medical school. In that then liberal city dissection of human cadavers was permitted, and possibly even vivisection of condemned criminals, all of which gave him a knowledge of human anatomy previously unattained. This was where Cleopatra was said to have allowed pregnant girls to be dissected so that the physicians could learn about human development (SAAWOK—IV, p. 429).

Herophilus is known only from references to him in the works of others, mainly of Galen. Had any of his works survived he would have been hailed as the Father of Human Anatomy. He knew a great deal about the nervous system (distinguishing sensory and motor nerves), blood system, and genital organs. He related the pulse to the beating of the heart and measured the pulse rate by using a clepsydra, a timing device that consisted of a container filled with water. The water dripped at a regular rate from a small hole and short intervals of time could be determined by counting the drops.

ERASISTRATUS

Herophilus' younger colleague, Erasistratus, was born about 304 B.C. on the island of Chios. The homelands of both Herophilus and Erasistratus were part of Ionia, now the western coast of Turkey and the nearby islands of the Aegean. The Greeks were not restricted to mainland Greece but had colonies throughout the Aegean and even along the coasts of the Black Sea, southern Italy, and elsewhere in the Mediterranean world. Ionia was famous for its scholars (Aristotle's ancestors were Ionians) and level of civilization (SAAWOK—IV, pp. 426–428).

We know more about Erasistratus than Herophilus. He appears to have been an excellent anatomist and even to have experimented. For example, he wondered about possible emanations from the body and placed a bird in a closed container with no food or water. The bird was weighed before incarceration, and afterwards, together with its feces. The final weight of bird plus feces was less than the initial weight. Therefore something, possibly emanations, had been lost. He dissected the brains of a hare, stag, and human being and correlated the extent of the convolutions with the animal's intelligence.

All parts of the body were thought to be served by a vein, artery, and nerve. The vein brought food in the form of blood, the artery brought *pneuma,* and the nerve *psychic pneuma.*

Blood was thought to be formed in the liver and distributed by the veins to all parts of the body. During the expansion of the heart, some blood enters the ventricle from the vena cava. This blood is pumped from the right ventricle through the pulmonary artery to the lungs. The tricuspid valve prevents the blood in the ventricle from returning to the vena cava and the semilunar valves prevent blood in the pulmonary artery from returning to the right ventricle. Blood reaches the other parts of the body through the veins.

There is an obvious problem here of distinguishing "artery" and "vein." The classical physiologists realized that the vessels connecting the heart and lungs were different from those in other parts of the body—just as today we emphasize to students that the pulmonary artery carries "venous blood" and the pulmonary vein carries "arterial blood." The ancient name for the pulmonary artery was "arterial vein" and, for the pulmonary vein, it was "venous artery."

Pneuma was thought to come from the atmosphere and pass through the nose to the lungs. It then goes in the pulmonary vein to the left ventricle. The ventricle contracts and sends *pneuma* through the arteries to all parts of the body. The bicuspid valve prevents the return of *pneuma* to the lungs. The lungs have no independent motion of their own. The chest expands and air rushes in because of *horror vacui*—that vacuum that nature was thought to abhor.

The *pneuma* carried to the brain was converted to *psychic pneuma.* This passes along the nerves to muscles, causing them to contract.

One might think at first that ignorance

is to be preferred to Erasistratus' "knowledge" of physiology. This is not the case. Although seemingly hopelessly wrong in many details, he was suggesting physiological principles that would prepare other investigators to think along lines that would become productive. He realized that arteries, veins, and nerves served all parts; that blood carries materials to those parts; that something in the air, *pneuma,* is required by the body's parts; that the brain, *via* the nerves, controls muscular contraction; that the heart pumped materials around the body; that the valves of the heart could control the direction of the blood's movement; and that physiological functions were to be explained in naturalistic terms.

Erasistratus' beliefs, like all statements of science are approximations to that elusive goal of "truth." Science is an accretive and self-correcting discipline and, generation after generation, its concepts become more precise and accurate. Many concepts have reached a stage where we say they are true beyond all reasonable doubt. Erasistratus was important in these developments because he recognized basic problems and suggested explanatory hypotheses that others could consider and test.

In a similar manner Aristotle's famous statement, that "Nature never makes anything that is superfluous" (*De Partibus* 691^{b}, 4), molded thought patterns in such a way that the concepts of adaptation and, finally, natural selection could be arrived at more readily. Most ideas that become important concepts probably start as rather fuzzy notions and it may take great effort to remove the fuzz and uncover the notion.

There is another noteworthy point concerning Erasistratus' knowledge of the function of arteries—and this tells us much about the pitfalls of scientific research. He knew that a cut artery of a living animal, which theory held contained *pneuma,* squirted blood. Rather than accept the evidence before him—that arteries as well as veins contain blood—he suggested a way out that would save the theory: when the artery was injured by the cut, it lost *pneuma* and, since nature abhors a vacuum, blood rushed in to fill up the space where the *pneuma* had been.

Scientists today, as always, see through the eyes of theory—the operational paradigm of the moment.

GALEN

Galen of Pergamum represented another important stage in the excruciatingly slow step to better knowledge of human form and function. He held hegemony over the minds of physicians, anatomists, and physiologists for far more than a millennium and was the last of the renowned Greek physicians of antiquity. In fact, he was the last notable human biologist until the 16th century.

Galen was born about 129 A.D. and died about 200. Pergamum was at this time a great center of Hellenistic civilization. It was part of Ionia—home to nearly all who established Greek science, and hence the science of today.

Galen began the study of medicine in his home city and then extended his knowledge in Smyrna and Alexandria. In Alexandria he was able to study human skeletons but the dissection of human cadavers was no longer permitted as it had been when Erasistratus was there. Apart from the scant information Galen would have acquired from treating wounds in his patients, his knowledge of human anatomy would have come from predecessors like Herophilus and Erasistratus. He realized, however, that the anatomy of other primates was almost identical with that of *Homo sapiens.* In fact much of his description of "human anatomy" is really that of the Rhesus Monkey and Barbary Ape.

After his studies, Galen returned to Pergamum and became a physician to the gladiators. This should have given him considerable experience with subcutaneous anatomy. When about 32 years old he went to Rome and began a most successful medical practice. He moved in high society and was a physician to many important people—the Emperor Marcus Aurelius was a patient and friend. After practicing in Rome he went home to Pergamum, then to Aquileia, and back to Rome for a second time.

His mentors were Hippocrates for medicine and Plato for philosophy. He refers frequently to Erasistratus of Alexandria, though not always in a fair and balanced manner. In many respects, Galen's knowledge was not much advanced over that of his famous predecessors. References to the time scale will put this in perspective. Hippocrates was born about seven centuries before Galen and Erasistratus more than four centuries before him. The equivalent antecedents for a biologist today would place one at about 1298 A.D. and the other at about 1554. A check of the biology of 1298 would have revealed a remarkable thing—the best source still would have been Galen! By 1554 the biological works of Aristotle were becoming better known, hence he joined Galen in being an unchallengeable authority. This was a sad fate for both, who had looked upon science as a way of knowing and not a corpus to be accepted on faith.

Galen's importance lies not so much in what he personally discovered but in his summarization of the entire span of Greek medicine from Hippocrates to his own times. And we must remember that much of what Hippocrates knew had come from much more ancient sources. Galen, then, summarized the profession as it had developed, painfully slowly, over a thousand years.

His basic approach was that espoused by Hippocrates: keep the person well by proper diet, exercise, rest, and a pleasing environment. For the patient he emphasized the importance of the physician making clinical observations in order to be able to identify the disease and to predict its course. Medical practice was to be based on the fact that the patient almost always recovers from an illness, except for the last. Thus "nature" is the healer. The primary role of the physician is to be sympathetic and supportive of the patient, not aggressive in fighting the disease. This was a most reasonable approach in those periods of medical history when both the nature of disease and effective cures were almost entirely unknown—at least the Hippocratic physician was unlikely to do harm.

Galen summarized and augmented knowledge of form and especially of function as well. His *On the Natural Faculties* [1916] is a general summary of his understanding of human biology. He had a great deal to say and some of his ideas will be mentioned. (*On the Natural Faculties,* or some of his other books, would provide a fine basis for a seminar for biology majors in which what Galen had to say could be evaluated in terms of our knowledge today.)

One of his most important principles was that the human organism is an integrated whole—hence his attempt to treat the whole body, not its constituent parts. By extension, this notion of an integrated whole could be held to apply to all organisms.

Galen held that there are three "faculties" of nature: embryonic development, growth, and nutrition. Nutrition results in the assimilation of food but before this can occur the food must be changed: "an assimilation of that which nourishes to that which receives nourishment" (I, xi) is required. He noted that it is necessary that the food be altered, otherwise how could beans, meat, bread, and other foodstuffs be changed to blood?

Food in the mouth is chewed and mixed with saliva. It is changed as can be shown by the fact that particles of food that remain between the teeth overnight are different from the original food.

Food remains in the stomach until it is properly digested then it moves through the pylorus. Its ability to pass into the pylorus is not a result solely of becoming liquid: if a pig is fed a mixture of flour and water, and cut open three or four hours later, the food is still in the stomach. Thus the processing of the food requires digestion and not merely breaking it down into small particles. It is only when the food is digested that the closed pylorus opens and the food leaves quickly. When the stomach is irritated by acidity, even if the food is not completely digested, it leaves the stomach prematurely.

The stomach undergoes peristaltic movements similar to those of the intestine. These are caused by the different coats in the wall. One coat causes traction and the other one peristalsis.

> For just as the movements in the [voluntary] muscles take place when each of the fibers shortens and draws towards its attachment, such also occurs in the stomach. When the transverse fibers shorten,

> the diameter of the cavity contained by them becomes less. When the longitudinal fibers contract the length must necessarily be shortened (III, viii; here and elsewhere Brock's translation is paraphrased).

Galen is remembered most frequently for his attempts to understand the functions of heart, lungs, arteries and veins. The problems relating to what we now call the circulatory and respiratory systems were those that ancient physiologists found most interesting and approachable. Galen's views were much the same as those of his predecessor of five centuries, Erasistratus. That is, blood is in the veins, *pneuma* in the arteries, and the heart pumps both to all parts of the body. Galen did add some correct notions but, unfortunately, added some errors as well. Progress in understanding was therefore about zero.

One of the correct notions was that blood as well as *pneuma* was, or could be, carried in the arteries. Here is one of his experiments:

> If you kill an animal by cutting a number of its large arteries, the veins as well as the arteries become empty of blood. This could never occur if there were not anastomoses between them (III, xv).

Thus, although Galen got blood into the arteries, he did not get the *pneuma* out. But note the very important implication: blood could pass between vein and artery.

Another important notion was that there is a circulation of sorts, at least in relation to the heart and lungs. Historians of science have often been confused about what Galen did believe but Fleming (1955) after a very careful analysis offers this version (I have substituted modern terms for the blood vessels and other structures):

> Blood on entering the right ventricle must pass by the one-way bicuspid valve inward, so that only an insignificant portion can relapse into the vena cava whence it came. Some of the blood passes directly from right to left through the interventricular septum. But much, and apparently most, of the blood moves into the pulmonary artery past the one-way semilunar valves from the ventricle. On contraction of the thorax, the blood in the pulmonary artery, its retreat cut off from behind, can only go forward into the venous system of the lungs. Whether the pulmonary veins then carry blood to the left ventricle is in question. He almost certainly thinks of the pulmonary vein as conveying the inspired air, in some form or another,—or at least some quality derived from the air,—from the lungs to the left ventricle. In the opposite direction smoky wastes are undoubtedly borne from the left ventricle to the lungs by way of the pulmonary vein. This process is made possible in Galen's view by the comparative insufficiency of the mitral valve opening into the heart. The blood in the left ventricle passes into the aorta through an aperture guarded by a one-way bicuspid or mitral valve.

Why those smoky wastes? It was believed that the heart produces heat and that, in turn, suggests a combustion of some sort. All familiar sorts of combustion produce a smoky residue along with the heat. The most likely way to rid the body of these wastes was *via* the lungs. This is an error, to be sure, but might it not have helped prepare the mind of others to accept that the body's heat is produced by processes not unlike those of ordinary burning? At least the heat was postulated as coming from natural processes and not as some sort of divine spark.

Galen is mainly remembered today for that seemingly egregious goof of believing that blood passes from the right ventricle to the left through pores in the interventricular septum. This is what he said:

> In the heart itself the thinnest portion of the blood is drawn from the right ventricle into the left through perforations in the septum between them. These perforations begin as pits with wide mouths and then become progressively narrower. It is not possible, however, actually to observe their extreme terminations, owing both to the smallness of these and to the fact that when the animal is dead all the parts are chilled and shrunken (III, xv).

It is fascinating to note how we evaluate individuals for proposing hypotheses that later prove to be correct compared with being incorrect. We may praise Galen for the hypothesis that somehow blood passes from pulmonary artery to pulmonary vein in the lungs, whereas we look unfavorably upon him for the hypothesis about the movement of blood through those pores in the septum between the ventricles. He had no evidence for either. His hypotheses were invented to account for problems he saw in the movement of blood. He was recognizing important problems and by suggesting possible hypotheses he was paving the way for others to determine whether the hypotheses are probably correct or probably incorrect. That is the way science works.

Nevertheless, it proved true that Galen became an obstacle to scientific progress. This was not his fault but that of those who came after him. His synthesis of human biology and medicine was the most magnificent available to the Western World from the 2nd to the 17th century. Those who came after him did not imitate his inquisitive mind but only revered his words. Along with Aristotle the two were the final arbiters of "truth." If nature appeared to be at variance with their statements, that showed that either the observer or nature must be at fault. Those were the fates of the two great biological scientists who began and ended the Greek miracle.

Galen had very definite ideas about the correlation of the parts of the body in different organisms—a thesis to be developed centuries later by Cuvier and others and become one of the cardinal principles of comparative anatomy. The following excerpts are modified from Chapter 1 of Book VI of *On Anatomical Procedures* [1956].

> Those apes with arms and legs most resembling those in man lack both long canine teeth and long faces. Such apes have an upright gait, speed in running, a thumb on the hand, a temporal muscle, hair variously hard and soft and long and short. *If you observe one of these characters, you can be sure of the others, for they always go together* [italics added]. Thus if you see an ape running swiftly upright, you may assume without close inspection that it is like a man. you can predict also that it has the other characteristics, namely, a round face, small canine teeth, and a moderately developed thumb. . . . On the other hand, if any of these characteristics is different, all of the others will differ. . . .

We observed the germ of this idea in Aristotle as well.

In *On the Natural Faculties*, Galen not only tries to give as accurate accounts as possible of human physiology but he criticizes those of his contemporaries who seem ignorant of facts or who espouse unproven notions. Apparently the medical profession was at a low point in the 2nd century A.D. He expressed the following modest hopes for his book.

> I am not unaware that I shall achieve nothing at all or very little. For I find that a great many things which have been conclusively demonstrated by ancient authorities are unintelligible to most individuals today because of their ignorance—and that because they are too lazy to learn. Even when they do understand they may not give an impartial account.
>
> The fact is that he who wishes to know more than the multitude does must far surpass all others as regards his nature and early training. When he reaches early adolescence, he must become possessed with an ardent love for truth—like one inspired. He must spend night and day learning thoroughly all that has been said by the most illustrious ancient authorities. Having learned all this, he must spend a prolonged period testing—observing what agrees with the ancient authorities and what does not—accepting one and rejecting the other. To such individuals my hope is that my treatise will prove of the very greatest assistance.
>
> Yet such people may be few in number. For the others this book will be as superfluous as a tale told to an ass (Book III, x).

Among "those other asses" were, in Galen's opinion, many of the Roman physicians of his time.

THOSE RATIONAL GREEKS?

This Essay and the two previous ones (SAAWOK—III, —IV) have surely left the reader with the impression that the Greeks were truly a group apart from all other ancient people. They discarded supernatural explanations and based their view of nature on what their senses told them, together with a rational analysis of those observations. They were inquisitive and had a burning desire to *understand.*

There is no doubt that the Greeks, Aristotle and Galen, were better biologists that the Romans, Pliny and Aelian. However, it is doubtful that the Greek and Roman masses differed in any appreciable manner from one another. The Greek miracle in biological science was based on a handful of individuals who probably had very little influence on their fellow citizens.

But progress in the arts, sciences, politics, and technology is always the product of a few individuals working in an environment that makes that progress possible. Thus, for our purposes, it is important to emphasize the accomplishments of the outstanding intellectuals of an age rather than attempt a Gallup Poll of general opinion. Progress is a matter of chance and necessity: the chance appearance of a talented mind plus the absolute necessity of a favorable environment in which that mind may flourish. Such an environment was available for those interested in the biological sciences for a century or so in ancient Greece and later in Alexandria.

Seemingly such was not the case in Rome where the genius of its most talented citizens turned to the problems of government, world conquest, empire, architecture, and public works instead of the sciences.

By the time of Galen's death the slow decline of the Roman Empire was underway and in a few centuries it was to be replaced by a society in which the intellectuals held totally different views of nature and the place of human beings in it. Naturalistic patterns of thought were to be replaced by the supernatural—a return to the Oriental mode. The Greek vision was to lie dormant for centuries as the Judeo-Christian world view prevailed among the finest minds of those times and, as well, was pressed upon the multitudes. Progress in those aspects of civilization that require an unfettered mind—pure and applied science and the arts—came nearly to a halt.

WHY?

Answers to "Why?" questions in history are equivocal at best. Nevertheless the decline and fall of ancient science was so striking and so complete that it deserves consideration. This is the analysis of Benjamin Farrington (1949, vol. 2, pp. 163–165).

> When modern science began in the sixteenth century it took up where the Greeks left off. Copernicus, Vesalius and Galileo are the continuators of Ptolemy, Galen and Archimedes. . . . The Greeks and Romans stood on the threshold of the modern world. Why did they not push the door open? The situation is paradoxical in the extreme. . . . Long before [the death of Galen in A.D. 199] the essential work had been done.
>
> Before the end of the third century B.C. Theophrastus, Strabo, Herophilus and Erasistratus, Ctesibius and Archimedes had done their work. In the Lyceum [in Athens] and Museum [in Alexandria] the prosecution of research had reached a high degree of efficiency. The capacity to organize knowledge logically was great. The range of positive information was impressive, the rate of its acquisition more impressive still. The theory of experiment had been grasped. Applications of science to various ingenious mechanisms were not lacking. It was not, then, only with Ptolemy and Galen that the ancients stood on the threshold of the modern world. . . . They had already been loitering on the threshold for four hundred years.
>
> Here, then, we have evidence of a real paralysis of science . . . there was no great forward drive, no general application of science to life. Science had ceased to be, or had failed to become, a real force in the life of society. Instead there had

arisen a conception of science as . . . liberal studies for a privileged minority. Science had become a relaxation, an adornment, a subject of contemplation. . . .

When we look for the causes of this paralysis it is obvious that it is not due to any failure of the individual. . . . The failure was a social one. . . . The ancients rigorously organized the logical aspects of science, lifted them out of the body of technical activity in which they had grown or in which they should have found their application, and set them apart from the world of practice and above it. This mischievous separation of the logic from the practice of science was the result of the universal cleavage of society into freeman and slave. This was not good for either practice or theory.

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THE JUDEO-CHRISTIAN WORLD VIEW

All belief systems tend to close the mind. If one is wholly committed to democracy, it is less easy to appreciate other forms of government. If one truly believes in the dogma of one religion, one cannot accept fully the dogma of others. True belief itself means the acceptance of some things and the exclusion of others.

Throughout human history the dominant belief systems of the majority have been some form of religion that often includes a moral code and some force or deity that can, at will, abrogate the laws of nature. It is with this supernatural element that we will be concerned.

There had been no competing belief system to challenge the religious mode of thought until the Ionian Greeks proposed to explain the phenomena of nature in objective terms. This mode of naturalistic thought appealed to some of the greatest thinkers of all times but its brief moment in the sun in the Western World was succeeded by the Dark Ages, when the intellectuals returned to the religious mode. There is little evidence that intellectuals in other parts of the world ever abandoned the religious mode.

There are fundamental differences between these two modes of thought. The received beliefs in religion are ultimately based on revelations and/or pronouncements usually by some long-dead person. These revelations and pronouncements become the dogma of the faith. Dogma is interpreted by a caste of priests and is accepted by the multitude on faith or under duress. Acceptance of a common dogma is one of the most cohesive forces in society, so not surprisingly it tends to be forcefully promoted by priests and rulers, who may be greatly rewarded by so doing.

In contrast, the statements in science are derived ultimately from the data of observation and experiment, and from the manipulation of these data according to logical and often mathematical procedures.

Since religion is not based on confirmable data, one can expect a great range of opinions about what it is and what it stands for. The following describes a fundamentalist type of Judeo-Christian thought that has been widely accepted to this day and probably would not have been objected to by the Fathers of the Church: There is a supernatural person or force, God, who looks out for the welfare of individuals, especially those who worship him. There is a life after death for human beings and this may involve a close association with God. Individuals can request the assistance of God by prayer and it may be granted. For the most part God leaves the working of the world to the natural order, but He has the power to override the laws of nature and do miraculous things—miracles being important evidence for God's existence. According to the theologian McKenzie (1965, p. 578).

> Modern theology defines miracle as a phenomenon in nature which transcends the capacity of natural causes to such a degree that it must be attributed to the direct intervention of God. This definition presupposes a conception of "nature" as a unity and a philosophy of nature and of natural "laws." The law of nature is a constant mode of action rooted in a fixed principle of the natural body; a miracle can be discerned because the constancy of the action and the constancy of the principle permit the observer to see beyond doubt that nature itself is incapable of producing the effect in question.

A belief in miracles probably played a great role in convincing people that their God must be all powerful because he could do such extraordinary things.

There are numerous examples of miracles in the Old Testament. For example: a bush spontaneously catches fire yet is not consumed—a double miracle (*Exodus* 3:2–6); snakes can talk to human beings in a language that human beings can understand—at least Eve could (*Genesis* 3); sticks can turn into snakes and then back again (*Exodus* 3:2–4, 7:10–12); or sticks can turn into maggots (*Exodus* 8:16–19); water can be changed to blood (*Exodus* 3:8, 7:17–22); skin diseases can appear and disappear in an instant (*Exodus* 3:6–7); the motion of the sun can be reversed (*Isaiah* 38:8) or even stopped entirely (*Joshua* 10:12–14); loud noises can make the battlements of a city fall down (*Joshua* 6:20); and, of course, the greatest miracle of all was the creation of the earth and its living inhabitants (*Genesis* 1–2).

Between the times the Old and New Testatments were written, the Mediterranean world had experienced the extraordinary phenomenon of Greek science and philosophy. This was a new way of thinking that influenced all intellectual activity. The conquests of Alexander carried Greek culture throughout the classical world, where it became known as Hellenistic civilization. Israel, as well as all other regions, were deeply affected. Secular Jews played an important role in Hellenistic times.

Nevertheless, Greek naturalistic thought seems to have had no influence on those who wrote the New Testament. The New Testament is as full of miracles as is the Old Testament. There are reports of walking on water, raising the dead, casting out demons, instant curing of long-standing diseases, calming storms, vastly increasing the quantity of loaves and fishes, etc. to quote McKenzie again (p. 579),

> The [New Testament] likewise, although it was written after the birth of [Greek] philosophical and scientific speculation, shows little or no conception of nature as a systematic unity governed by fixed principles and laws of causality. The [New Testament] conception of God and nature is much more a reflection of the [Old Testament] conception than it is of the [Greek] idea.

THE BISHOP OF HIPPO

The Old and New Testaments were available to the Christians of the early centuries A.D. They were accepted as divinely inspired and became the spiritual basis of Christianity. There were, however, varying interpretations of what the Bible was saying. A series of brilliant scholars attempted to discover what, indeed, was the message. Among these no one in the early days of the Church was more important than St. Augustine. He, more than anyone else, set the pattern for Christian belief because of the sheer magnitude of his published works and the intellectual quality of his arguments.

As the centuries passed Christian dogma was to become more and more based on interpretations of Scripture rather than on Scripture itself and Augustine was central to this development. He attempted to explain such a difficult theological matter as the nature of the Trinity. It is not immediately apparent how three entities—God the Father, Christ the Son, and the Holy

Ghost—are really one or why it is important to claim that they are. Neither is it clear how a seemingly minor action by Adam, the original sin, is inherited by all mankind for all time. Augustine discussed these and many other matters and in so doing established the field of theology.

Augustine was born in 354 A.D. in North Africa, when it was a highly civilized part of the Roman world. He became bishop of Hippo, also in North Africa, where he died in 430. He was active, therefore, about two centuries after Galen. This was a critical period for Christian religion and for the Roman Empire. The former was increasing in importance and power and the latter was declining and about to fall. Augustine died as Hippo itself was under siege and about to fall to a Germanic tribe of barbarians, the Vandals.

Although St. Augustine's interests were overwhelmingly theological, he did express opinions about natural events. For example he said that natural phenomena are to be explained by theological methods. Moreover, nothing is to be accepted save on the authority of Scripture, since that authority is greater than all the powers of the human mind.

Augustine held that, at the beginning of Creation, matter was made from nothing. When asked what the Creator was doing before he created the world, he replied that he would not quip, as others had done, that God "was preparing hell for people who pry into mysteries." It is better, he said, just to admit that you do not know.

The problem of the two accounts of Creation in *Genesis* was "solved" by assuming that Creation took place both in six days and in an instant. He thought that there was a good reason for six days: six is the first perfect number but we must not say that it is a perfect number because God finished all his works in six days but that God did so in six days because six was a perfect number. But the second account of Creation gave no time limit so it had been decided that it had occurred in an instant. For the most part, Augustine read the accounts of Creation in *Genesis* as literally as possible. Nevertheless, some statements were not readily understandable and, hence, he and the greatest minds of the age attempted interpretations.

Augustine held open the possibility that not all creatures appeared fully formed during the first six days of Creation. Some might have remained as dormant "seeds" and become activated later:

> Just as the seed contains all that is necessary in the course of time to grow into a tree, so the universe must be conceived as having had at the same time all things that were to be made in it since God created all things at the same time. [Included here are] also those things which earth and water produced potentially and causally prior to the time they came into being in the form they are now known to us (*De Gen. ad litt.*, V, xxiii).

Not only was God the Creator but He is necessary for the continued existence of all creatures:

> Indeed the power . . . and strength of the Creator . . . is for each and every creature the cause of its continued existence. . . . If this strength were at any time to cease directing the things that have been created, they would cease to be (*De Gen. ad litt.*, IV, xxii).

Augustine believed in the fixity of species:

> A bean does not grow from a grain of wheat, nor wheat from a bean. A beast does not give birth to a man, or a man to a beast (*De Gen. ad litt.*, IX, 32).

Some animals, such as frogs, mice, worms, and flies, were thought to be quite superfluous since they seemed to have no importance to human beings.

Saint Augustine forcefully insisted on the authority of the Church, basing his view on Apostolic Succession. This was the belief that, beginning with the Apostles, there had been a God-directed succession of bishops of the Church whose opinions were reflections of God's will. The Pope, as Bishop of Rome, was held to be preeminent because he was in direct succession from the Apostle St. Peter, the "rock" upon which Christ said the Church would be built.

All this may seem of little importance to the development of science but quite the contrary. If Christianity had been just another one of the innumerable religions springing up in the dying Roman Empire, Augustine's claims for complete authority and by implication for infallibility for the Church might have been regarded merely as arrogant or amusing. But the Church was to become the dominant religious, political, and intellectual force after the passing of Roman civilization. As its power increased, so did its ability to demand obedience to what it claimed to be "truth." So Augustine's views became important because the Church became powerful.

It is hard to think of any attitude more devastating to science or any intellectual discipline—even theology. Knowledge comes only if there is the freedom to seek it. Had the Church restricted its authority to matters of religion and morals, it might not have inhibited the growth of science. However, it claimed authority for everything on the basis of what it interpreted the Bible to be saying. A literal interpretation of scripture had the sun rising and setting, so any proposal that the apparent motion of the sun was a consequence of the earth's rotation was heresy and was to be dealt with as the gravest of sins.

Augustine's view of nature was to play an important role. He accepted, of course, that nature was the work of God and as such was important. It was clear to him, however, that the significant thing was to try to know God, so any interest in living creatures would be only for that purpose.

> The eyes love beautiful and diverse shapes, brilliant and pleasing colors. Let these things not occupy my soul; let God occupy it, who indeed made all these things which are very good, still He is my God, not these things (*Confessions*, Book 10, Chapter 34).

There was a more practical reason for not wasting time on nature study. The Bible was interpreted as indicating that the end of the earth was nigh. In the little time left there were more important things to do than to study the products of creation.

The Creator had infused filth and carrion with the power to generate insects, worms, and many smaller creatures. This hypothesis made Noah's task of assembling *all* creatures in the Ark far simpler—and Adam would not have the huge task of giving names to all of them.

Augustine had great difficulty understanding how wild animals living in far away places could reach the Ark. He suggested that the transfer may have been accomplished by angels who were commanded to perform this task by God.

Although most of the theologians of the early Church read the scriptures as indicating a flat earth, Augustine was not so sure.

He reported seeing a huge tooth—surely a fossil but he would not have known that—and assumed that it had come from a giant of olden days.

There were fierce theological debates about the age of the earth—some claiming six thousand years others four thousand. There was a strong argument for six thousand: since Adam had been created on the sixth day, it was reasonable to assume that the second Adam, Christ, would come after six thousand years. In any event, Augustine believed one of the greatest heretical opinions would be to accept that Creation had taken place more than six thousand years ago.

Augustine was vehement in denouncing the view that human beings lived at the Antipodes, that is on the opposite side of the earth. If they did, they would not be able to see Christ descending from the heavens at the Second Coming.

The air was thought to be full of devils, which were responsible for violent storms.

He believed in miracles and magic, recounting that a drug placed in cheese could cause people to change into animals. He also taught that bones of the saints could heal the sick and that sickness was the result of demons.

Augustine and most other theologians denounced the dissection of the human body. Such a view had been expressed by an earlier theologian, Tertullian, who had denounced that Father of Anatomy, Herophilus, who had based his conclusions about the human anatomy on first hand experience. This prohibition against cutting into the human body had some strange consequences—among others the cessation of removing the flesh from the bones of fallen Crusaders. This procedure had made it more convenient to carry their bones home for burial. Tertullian is remembered also for saying that "the blood of martyrs is the seed of the Church" and that "It is certain because it is impossible." The last will take care of any intellectual difficulty that does not conform to possibility.

Augustine taught that all of nature was good and all was the work of the Creator. If this was so, then life had a history—it had neither existed forever nor had it undergone a series of cycles as some Oriental religions maintained. It would have had a beginning, a period of increase as it populated the earth, and presumably it was to have an end. This was not evolutionary thinking but it did prepare the mind for change over time—a point of view that was a major step along the road of making biology a more conceptual science.

Again and again, in reading Augustine, one notes that much of what he believed about nature survives in the minds of many people to this day.

To Augustine it was necessary to remember the final goal—trying to know God—and not to be distracted by an undue interest in worldy phenomena:

> To this, another kind of temptation joins company, one dangerous in many ways. For, over and above the concupiscence of the flesh which finds a place in the enjoyment of all sensations and pleasures, to which they who put themselves far from Thee become slaves unto their perdition, there is present in the soul through the same bodily senses a certain vain and curious desire—cloaked under the name of knowledge and science—not for fleshy enjoyment, but for gaining personal experience through the flesh [*i.e.,* the sense organs]. Because this consists in the craving to know, and the eyes are the chief agents for knowing among the senses, it has been called the concupiscence of the eyes in holy Scripture (*Confessions,* Book 10, Chapter 35).

Augustine's reference to the "holy Scripture" is to be found in the *First Letter of John* 2:15–16.

> Do not set your hearts on the godless world or anything in it. Anyone who loves the world is a stranger to the Father's love. Everything the world affords, all that panders to the appetites or entices the eyes, all the glamor of its life, springs not from the Father but from the godless world.

Augustine reads St. John as saying that a search for knowledge of earthly things is dangerous.

There is no question, however, that St. Augustine discouraged free inquiry about earthly matters. And as theology developed, free inquiry about religious matters became a hazardous enterprise as well—if you happened to hold a point of view that was eventually decided to be wrong by more powerful individuals in the Church. There were innumerable arguments in the early Church about original sin, the sacraments, the Trinity, life at the Antipodes, matrimony, the Mass, invocation of the saints, authority of the popes, relics, demons and devils, the nature of sickness, inerrancy of the Bible, date for Easter, baptism, and so on. The point of view that lost in a debate became a "heresy," and those who continued to uphold such a view were "heretics." Later a special institution, the Inquisition, was established to deal with these wrong-thinking people.

Critics of the early Christian Church often blame it not only for the destruction of Roman civilization but for the destruction of science as well. So far as Roman civilization was concerned, it can be argued, however, that Christianity was only one of many factors that hastened Rome's fall. Decline and periods of anarchy were occurring as early as the 3rd century A.D. Even then the Empire was about to be divided, since a single center at Rome could not rule the provinces and defend the frontiers. Eventually the Empire was divided into an eastern part, ruled from Constantinople and a western part, ruled from Rome. In 313 the Emperor Constantine granted religious freedom to all, which lessened the persecutions of the Christians—for a time—and began a spectacular increase in their numbers and importance. By the end of the 4th century, Rome had lost most of its political importance. The city was sacked several times by Germanic invaders and the last Roman Emperor in the West was deposed in 476. Western civilization was replaced by anarchy and the Catholic Church was the sole institution of stability and power. It was inevitable, therefore, that its authoritarian belief system would replace all others.

As for the charge that Christianity destroyed science, it is clear that there was hardly any to destroy. Rome made little contribution to science and even Greek science was passing into oblivion. If we take the date of the Fall of Rome to be 476 A.D., we are talking about a time *eight centuries* after Aristotle. As we have seen already, Aristotle did not usher in a period of sustained achievement in science—in fact, it peaked with him and then declined. There was no important Roman science whatsoever. There was a brilliant, though brief, period of Hellenistic science centered in Alexandria in the two centuries before its absorption into the Roman Empire in 30 B.C.

Nevertheless, it is true that the attitude of the Church prevented the development of science for more than a thousand years and inhibited it for centuries thereafter—and does so to some extent to this day.

Possibly those practical Romans saw no utility in science for science's sake. One could not argue that the biological problems that were of interest to Aristotle would be useful in commerce, industry, agriculture, or even human health. This was largely true of medical research as well. Knowledge of human anatomy and physiology, as synthesized by Galen, was of little importance in those days when diseases could not be recognized with certainty and, if they were, no effective medicines were available to cure them. Getting well depended to a large degree on "letting nature take its course." The outcome of illness would be the same whether or not the arteries contained *pneuma* or whether or not blood passed through those invisible pores in the interventricular septum.

Scientific knowledge did not become obviously useful until centuries later nor did it expand to any appreciable degree. We draw the curtains, therefore, for a thousand years. During that long period the writings of St. Augustine were of basic importance but not for science. During the Middle Ages the intellectual's challenge was to be found in the problems of theology. This is how the historian Andrew Dixon White (1898, vol. 1, p. 32) summed it up:

> But, as a matter of course, in the early Church and throughout the Middle Ages all such studies [of nature] were cast in a theologic mould. Without some purpose of biblical illustration or spiritual edification they were considered futile; too much prying into the secrets of Nature was very generally held to be dangerous both to body and soul; only for showing forth God's glory and his purposes in the creation were such studies praiseworthy. The great work of Aristotle was under eclipse. The early Christian thinkers gave little attention to it, and that little was devoted to transforming it into something absolutely opposed to his whole spirit and method; in place of it they developed the *Physiologus* and *Bestiaries*, mingling scriptural statements, legends of the saints, and fanciful inventions with pious intent and childlike simplicity. In place of research came authority—the authority of the Scriptures as interpreted by the *Physiologus* and the *Bestiaries*—and these remained the principal source of thought on animated Nature for over a thousand years.

THE BOOK OF BEASTS

The *Physiologus* began as a Greek work of the 3rd century A.D. The title means "One who knows nature" and rarely has there been a more inappropriate title. Most of the information and some of the animals included were imaginary. The purpose was to use information about animals allegorically. That being the case, it was not too important that the information be correct. The *Physiologus* presented the Christian view of the Animal Kingdom.

The *Physiologus* was widely copied and modified and these copies also went by the title of *Bestiaries.* They were collections of stories about animals, real and imagined, that were modified to illuminate principles of morality and allegorical interpretations of the Bible and Church doctrine. The following excerpts from the discussion of lions in a 12th century *Bestiary* gives the flavor (modified from T. H. White, 1954):

> Scientists say that Leo has three principal characteristics. The first is that he loves to saunter on the tops of mountains. Then, if he should happen to be pursued by hunters, their smell reaches up to him, and he then disguises his spoor with his tail. Thus the hunters cannot track him.
>
> It was in this way that our Saviour, the Spiritual Lion of the Tribe of Judah, once hid the spoor of his love in the high places. When sent by his Father he came down and into the womb of the Virgin Mary and saved the human race which had perished. . . .
>
> The Lion's second feature is that he seems to sleep with his eyes open.
>
> In this very way, Our Lord while sleeping in the body was buried after being crucified. Yet his Godhead was awake. As it is said in the *Song of Songs,* "I am asleep and my heart is awake," or in the Psalm, "Behold, he that keepeth Israel shall neither slumber nor sleep."
>
> The third feature is this. When the lioness gives birth to her cubs, they are dead and are lifeless for three days. Their father comes on the third day and breathes on their faces and makes them alive.
>
> Just so did the Father Omnipotent raise Our Lord Jesus Christ from the dead on the third day. Quoth Jacob: "He shall sleep like a lion, and the lion's whelp shall be raised."

Other information about lions mentions that they go wherever they wish; have litters of three; they fear creaking wheels, fires, and cocks—especially white ones; they are compassionate; they prey on men but not women—and on children only when very hungry; they do not overeat and, in fact eat only on alternate days; toothlessness is a sign of old age; they copulate backwards; their first litter consist of five, next year four, and successively to one after which they are sterile; they eat only fresh food; their roar is terrible; when sick they eat a monkey and get well; although they are the king of beasts the poisons of scorpions and snakes can kill them.

Thus the Animal Kingdom was viewed as a reflection of Christian doctrine and all intellectual interest in nature was organized on that basis. Animals and plants were thought of as symbols for various traits, and as such they played a most important part in the art of the Renaissance. Thus the reason that paintings of the Nativity usually include an ox and an ass can be traced to *Isaiah* 1:3, "The ox knoweth his owner, and the ass his master's crib." The basilisk, a mosaic of rooster and snake, was regarded as a symbol of the devil; the bee of industry; the bull of strength; the camel of temperance (it can go without drinking for many days); the cat of laziness; the cock of watchfulness; the dog of fidelity; the dove of peace; the fly of sin; the fox of cunning; the locust of plagues; the hog of gluttony; the lamb of Christ (*John* 1:29—"Behold the Lamb of God"); the lion of courage; the peacock of immortality (it was believed that its flesh would not decay); and so on.

Even to this day we attribute specific virtues to animals—fidelity of dogs, for example—that trace back to the Medieval *Bestiaries.*

One fascinating example in a *Bestiary* of relying on ingenuity when facts failed is the ant-lion. Apparently the Hebrew text of *Job* 4:11 referred to a lion-like animal but the term used was unfamiliar to those preparing the *Septuagint* translation of the Old Testament. They had heard of a mammal similar to a lion that lived in Arabia. Its name was "myrmex." The translators

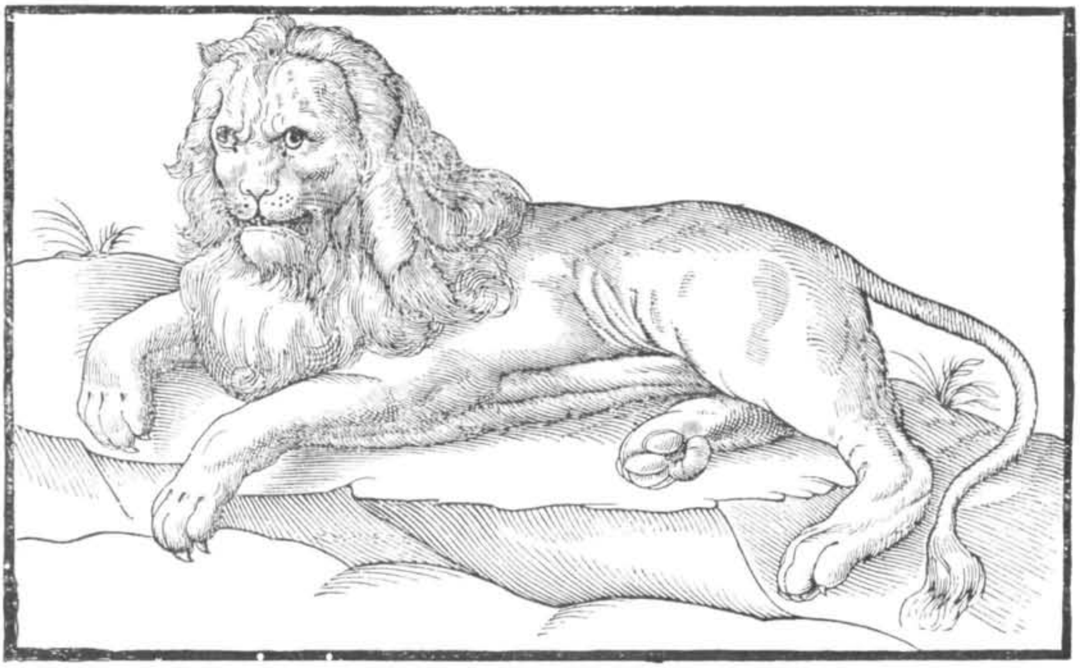


FIG. 17. Illustrations from Topsell. The lion (above) is an accurate representation. The same can not be said for the rhinoceros on the right page. The artist must never have seen a rhinoceros and have relied on descriptions and crude illustrations. Note, for example, the position of the second horn.

then combined myrmex with the Greek word for lion and came up with "myrmekoleon," or "ant-lion." Hence Job was interpreted as saying that myrmekoleon was unable to eat. It is easy to see why this might be so as the *Physiologus* explains (T. H. White, 1954, p. 214):

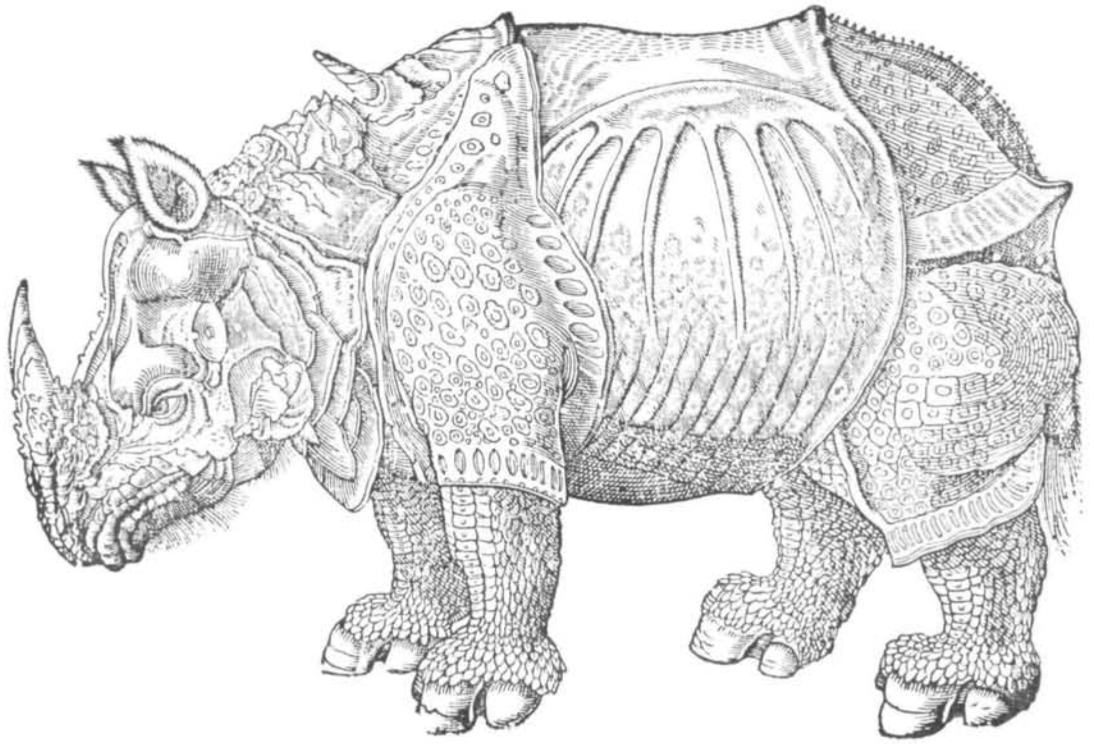
> It had the face (or fore-part) of a lion and the hinder part of an ant. Its father eats flesh, but its mother [an ant] grains. If they then engender the ant-lion, they engender a thing of two natures, such that it cannot eat flesh because of the nature of its mother, nor grains because of the nature of its father. It perishes, therefore, because it has no nutriment.

GESNER AND TOPSELL

By the 16th century the *Bestiaries* were losing their influence because books about animals more in the style of Pliny or Aelian—that is, folklore but without Christian symbolism—began to appear (Figs. 17, 18). The most famous of these was the *Historiae Animalium* published in five volumes, from 1551 to 1587, by the Swiss naturalist, Conrad Gesner (1516–1565).

This was translated into English and expanded by Edward Topsell (*ca.* 1572–1638) as *The History of Four-footed Beasts* (1607 and many later editions).

We can compare his approach to the lion with that of the 12th century *Bestiary* just described. Topsell provides 25 large pages of information, as the importance and dignity of the lion requires that much attention. He notes the names used for the lion in various languages and the references to this animal in the Bible. Other animals may beget lions. For example, a concubine of the first king of Sardis bore him a lion. The soothsayers told the king that all places in Sardis where this lion walked would be safe forever. So the lion was taken round all the towers and battlements except for one—and years later that



is where the soldiers of Darius breached the walls and took the city of Sardis.

Topsell notes that lions are found nowhere in Europe except in Greece. Essentially all that he has to say about lions comes from the literature and this included a modicum of description and many stories about lions. The one about the lion's fear of white cocks is included—just as it was in the 12th century *Bestiary* and in Pliny as well.

Topsell describes the uses, mainly medical, of the species he discusses. Blood of the lion will cure cankers and, if smeared over the body, will protect human beings from all wild beasts; lion grease is equally protective; eating the flesh will prevent bad dreams; shoes made of lion skin will prevent gout; by smearing the body with fat from the lion's kidney, one will be protected from wolves; lion fat or feces can be mixed with ointments and used to cure acne; lion grease plus oil of roses as well as dried heart powder cure quartan malaria; lion brains, when taken in drink, drive one mad; lion gall is useful in jaundice and eye diseases; fat from the lion's private parts can prevent conception. This is only a portion of the lion pharmacopoeia. Lion fat, especially, can be mixed in many ways to work all sorts of cures.

Topsell pays much attention to the lesser creatures as well. He records the information from the literature relating to "The Vulgar Little Mouse" and then describes its medicines. A mouse can be skinned, cut in two, and placed over an arrow wound to help the healing process; if a mouse is beaten into pieces and mixed with old wine, the concoction will cause hair to grow on the eyelids; if skinned, steeped in oil and rubbed with salt, the mouse will cure pains in the lungs; sodden mice can prevent children from urinating too much; mice that are burned and converted to powder are fine for cleaning the teeth; mouse dung, prepared in various manners, is useful for treating sciatica, headache, migraine, the tetters, scabs, red bunches on the head, gout, wounds, spitting of blood, colic, constipation, stones, for producing abortions, putting on weight, and increasing lactation in women.

All this is a very far cry indeed from Hippocrates and his benign, rational medicine. How could it be that, generation after generation, people would put their faith in what Hippocrates of long ago and we today would regard as nonsense? Part of the answer is that when people are sick they want *something* to be done. In the absence of effective medicines, that something is likely to be anything—especially if the taste is terrible and the source is repulsive. That point of view goes back to the demons-are-the-cause-of-disease period when the effectiveness of the medicine depended largely on its being so unpleasant to the demons that they would depart forthwith from the patient. A more potent reason is that these medicines from the "vulgar little mouse" could be imagined to be effective cures—after all, sick people nearly always get well on their own. If they had used mouse dung in order to get well, and had gotten well, surely the remedy was effective—Q.E.D. And we must not forget the admitted and well documented power of placebos. In short, mouse dung *can be* effective—if one has faith that it will be.

We must not forget, either, that there are millions of individuals in the world today whose level of knowledge about animals and disease shows no advance over that of Topsell. But knowledge of the living world was improving so we can recognize Topsell as closing out the biology of the Middle Ages. His *History* is a link between the fanciful, symbolic, theological descriptions of animals of the *Physiologus* and *Bestiaries* and more modern approaches to understanding animals. In the *Bestiaries* there is no emphasis on personal observations, the need to check data, and naturalistic descriptions. Nevertheless, Topsell was able to expunge most of the theology from his book.

The first edition of Topsell's *History of Four-footed Beasts* was published in 1607—the year that also saw the first permanent English settlement in the New World at Jamestown, Virginia. Since his was the first comprehensive treatment of animals in the English language, the history of our nation and of publications of general zoological works in the English language occupy the same period of time.

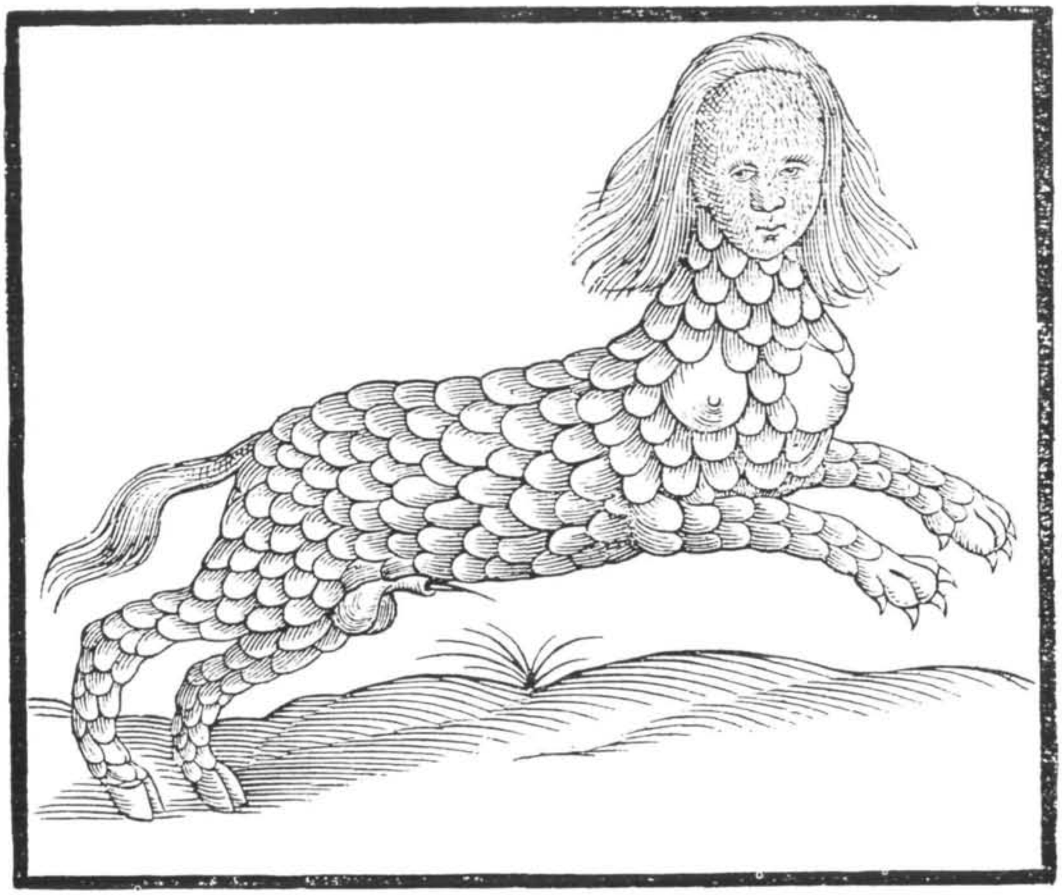
Islamic Science

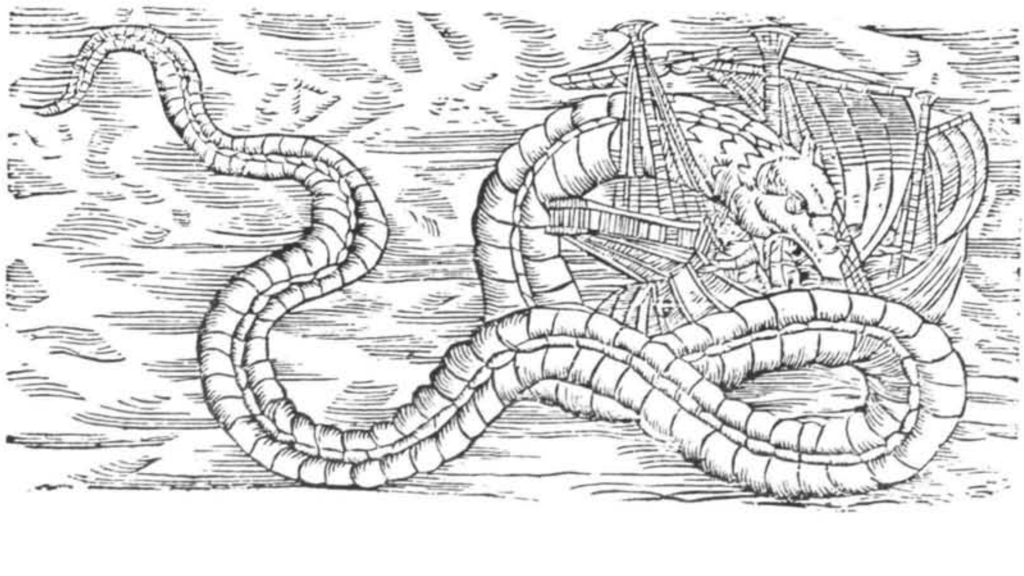
During those long centuries when the Western view of nature was dominated by supernatural explanations, Islamic civilization was at its peak. Learning in Islam was based on earlier Greek works. For example, in his famous *Canon of Medicine* Avicenna, or Ibn Sina (980–1037), combined the biology of Aristotle and Greek medical lore with what the Islamic physicians had discovered. When it became apparent that Islamic medicine was superior to that of Western Europe, Avicenna's *Canon* became an authority and remained so until the 16th century.

The Islamic scholars contributed greatly to mathematics and astronomy—most of the names we use today for the more prominent stars are Arabic. Nevertheless, their science was in the descriptive, data-gathering stage and there was little conceptual advance. Islamic scholars are given much of the credit for keeping Greek science and philosophy alive.

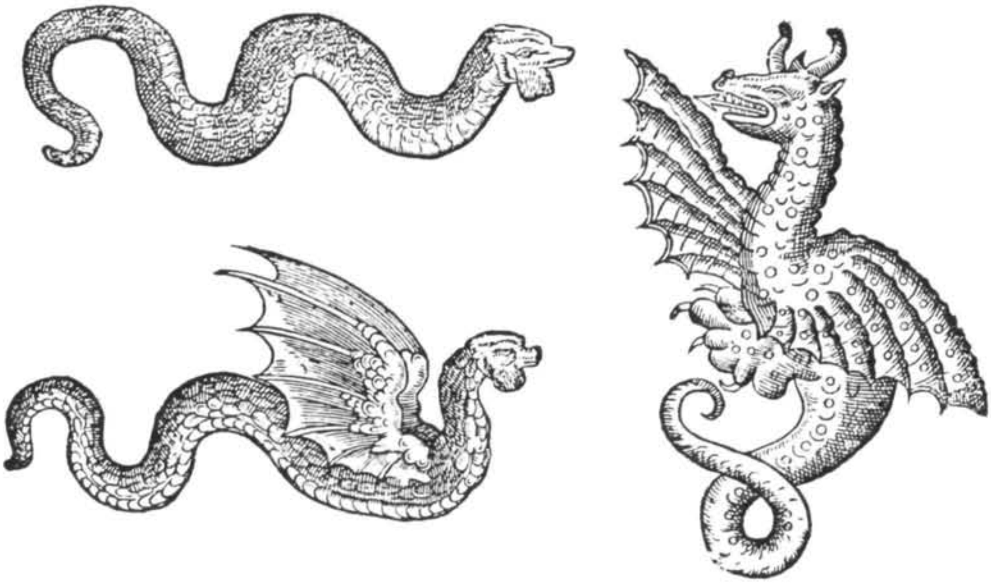
→

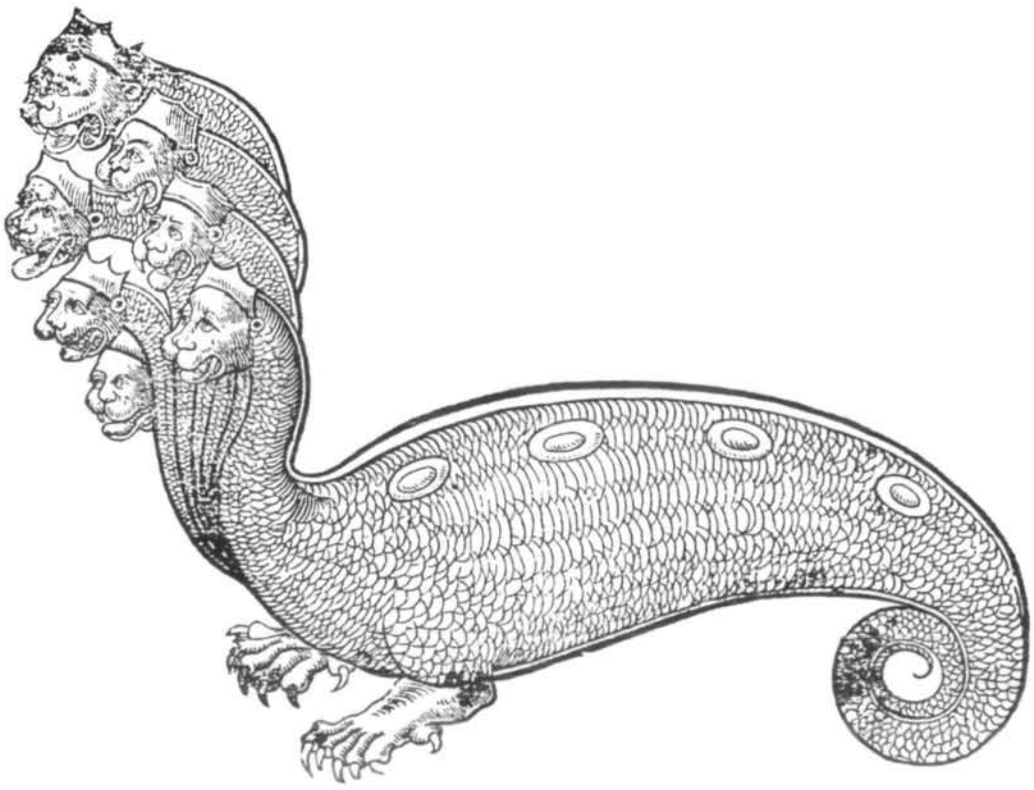
FIG. 18. Some fabulous creatures from Topsell are shown on the next three pages. The first is Lamia, part beautiful woman and part animal (not entirely female), about which there were a great variety of stories. Below here is a sea monster attacking a ship. Three varieties of dragon follow and then a fabulous creature, a hydra, with seven crowned heads and a single body. One report had it killed by Hercules. Another possible origin of such a creature may be *Revelation* 12:3 which reports a great red dragon with seven heads, with crowns. Michael got rid of him. Topsell seems to believe that this creature is "unpossible." The third page of plates begins with a satyre, followed by a cockatrice, or basilisk, which is the king of the serpents. They are born from eggs laid by roosters. Next follows a unicorn and finally an aegopithecus, a combination of ape and goat.

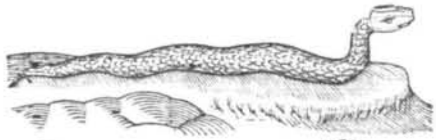


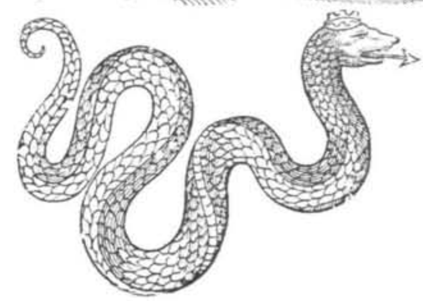


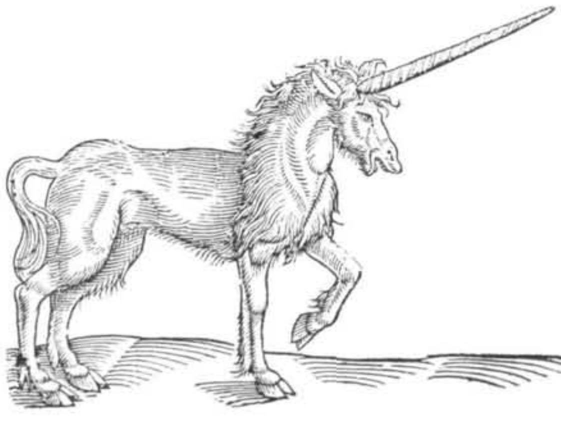
Of the DRAGON.











Their outlook on medicine, as contrasted with that then current in the Christian West, is shown by the following event that occurred in the 12th century and was reported by an Arab physician (Munro, 1903).

They brought to me a knight with an abscess in his leg, and a woman troubled with fever. I applied to the knight a little [poultice]; his abscess opened and took a favorable turn. As for the woman I forbade her to eat certain foods, and I lowered her temperature. I was there when a Frankish [*i.e.*, western European] doctor arrived, who said, "This man [meaning the Islamic physician] cannot cure them." Then, addressing the knight, he asked, "which do you prefer, to live with a single leg, or to die with both legs?" "I prefer," replied the knight, "to live with a single leg." "Then bring," said the doctor, "a strong knight with a sharp ax." The doctor stretched the leg of the patient on a block of wood, and then said, "cut off the leg with the ax,

> detach it with a single blow." Under my eyes the knight gave a violent blow. He gave the unfortunate man a second blow, which caused the marrow to flow from the bone, and the patient died immediately. As for the woman, the doctor examined her and said, "She is a woman with a devil in her head. Shave her hair." They did so; she began to eat again—like her compatriots—garlic and mustard. Her fever grew worse. The doctor said, "the devil has gone into her head." Seizing the razor he cut into her head in the form of a cross. Then he rubbed her head with salt. The woman expired immediately. After asking them if my services were still needed, and after receiving a negative answer, I returned, having learned from them medical matters of which I had previously been ignorant.

Ignorance does have its points. This vignette of the 12th century illustrates vividly the consequence of accepting an authoritative, dogmatic, supernatural belief system.

The End of the Era

Will Durant (1950, pp. 74–75), in his description of Augustine, appraises the mind of the Middle Ages—a mind that Augustine played such an important role in formulating:

> [Augustine's] subjective, emotional, anti-intellectual emphasis marked the end of the classical, the triumph of [the] medieval. . . . To understand the Middle Ages we must forget our modern rationalism, our proud confidence in reason and science, our restless search after wealth and power and an earthly paradise; we must enter sympathetically into the mood of men disillusioned of these pursuits, standing at the end of a thousand years of rationalism, finding all dreams of utopia shattered by war and poverty and barbarism, seeking consolation in the hope of happiness beyond the grave, inspired and comforted by the story and figure of Christ, throwing themselves upon the mercy and goodness of God, and living in the thought of His eternal presence, His inescapable judgement, and the atoning death of His Son. St. Augustine above all others . . . is the most authentic, eloquent, and powerful voice of the Age of Faith in Christendom.

So those thousand years of rationalism were to be followed in the West by a thousand years of war, poverty, intolerance, anti-intellectualism and barbarism of a level rarely equaled in the prior, more rational millennium.

References: The Judeo-Christian Tradition

The Judeo-Christian tradition lasts to this day, of course, but the following references are to that period in history when it provided the view of nature accepted by the scholars of an earlier age. See also SAAWOK—IV, pp. 428–430.

Ambrosius [1961], Arano [1976], Artz (1965), Augustine (1844, 1957, 1961), Bourke (1984), P. Brown (1967), Crombie (1959, vol. 1), Encyclopaedia Britannica (1911), Gesner (1558–1603), Haskins (1924, 1927), Knowles (1962), Ley (1968), McIntosh (1912), McKenzie (1965), McMullin (1970), van der Meer (1961), Munro (1903), O'Donnell (1985), O'Meara (1980), Pelikan (1971), Pope (1949), Portalie (1960), Przywara (1936), B. Russell (1945), J. H. Taylor (1982), H. O. Taylor (1951), Topsell (1658), A. D. White (1896), T. H. White (1954), and H. J. Wood (1924).

The Revival of Science

In the year 1543 there were two epoch-making publications in science: *De Revolutionibus Orbium Coelestium* by Nicholas Copernicus (1473–1543) and *De Humani Corporis Fabrica* by Andreas Vesalius (1514–1564). Although both books were but a stage in the slow rebirth of science, they represent such an important advance in understanding nature that we can recognize them as the beginning of the Scientific Revolution. That revolution is still underway but today the rapid advances in all the sciences are so taken for granted that we no longer speak of a "revolution."

Some giants of science who followed Copernicus in astronomy and were active in this revolution during the last half of the 16th and the early 17th centuries were Tycho Brahe (1546–1601), Johann Kepler (1571–1642), and Galileo Galilei (1564–1642). In addition, Galileo started physics on its modern course.

Following Vesalius some of the notable biologists were Fabricius of Aquapendente (*ca.* 1533–1619), William Harvey (1578–1657), and Marcello Malpighi (1628–1694) (their contributions to developmental biology were mentioned before in SAAWOK—IV, pp. 430–442) and Robert Hooke (1635–1703), who was to help open the world of the very small (SAAWOK—III, pp. 608–612).

Among other major contributors to the advance of science were Sir Francis Bacon (1561–1626), who insisted that science must be based on data not faith (SAAWOK—III, pp. 591–596), and the culminating presence of all, Sir Isaac Newton (1642–1727).

Important innovations helped make the Scientific Revolution possible and sustainable. Of exceptional importance, the invention of movable type by Johann Gutenberg (*ca.* 1397–1468) made it possible to print *identical* multiple copies of books. That invention was absolutely basic for reliable communication in science. No longer would the flow of information among individuals and between generations be dependent on the accuracy of a scribe who might not only introduce errors of transcription but, even worse, attempt to be creative. To this day, scholars of classical writings have great problems of knowing what was said by the ancient authors and what are errors or emendations made by later scribes.

The appearance of universities in Western Europe was most important for progress in science. Science requires interactions among individuals and traditionally universities have provided this community. Higher education was not readily available in classical times, although Plato and Aristotle had schools and the Library-Museum in Alexandria was noted for its scholarship. But such institutions were few and ephemeral. Universities appeared in the late Middle Ages and by the 16th century there were many in Europe. They prepared students for careers in theology, law, and medicine. They provided a forum where intellectual matters could be discussed. A vital service was the university library, which could maintain collections of books well beyond the means of single scholars.

Museums, which started anew in the 16th century, played an important role in the advancement of the biological sciences. Gesner (mentioned before), started a museum and soon others appeared in many European cities. Reliable scientific scholarship requires not only publications that are clearly written and well illustrated but the availability of actual biological materials. Consider the case of a 16th century naturalist describing a complex animal shell. That is hard to do with words alone; a good illustration would help greatly; the specimen itself would be the best of all.

But not many sorts of animals could be kept in museum collections. Soft bodied ones would rot quickly, since there was no way to preserve them. Some species could be dried—insects, for example. Zoological collections, therefore, had to be restricted to materials such as dried arthropods, the bones of vertebrates, shells of mollusks, hard parts of coelenterates (corals, sea fans, etc.), and skins of animals and birds.

However, in the early 1660s Robert Boyle (1627–1691), who first distinguished elements from compounds, recognized the nature of chemical reactions as well as the relations of pressure, volume, and temperature in confined gases, hit upon a way to preserve the soft structures of animals. He explained his method at a meeting of the Royal Society on 7 May 1666 (Boyle, 1666, pp. 199–200):

> The time of the year invites me to intimate to you, that among the other Uses of Experiment, I long since presented the *Society*, of preserving Whelps taken out of the Dams womb, and other *Faetus's*, or parts of them, in *Spirit of Wine* [probably about 85 percent alcohol]; I remember, I did, when I was sollicitous to observe the Processe of Nature in the Formation of a Chick, open Hens Eggs, some at such a day, and some at other

daies after the beginning of the Incubation, and carefully taking out the *Embryos,* embalmed each of them in a distinct Glass (which is to be carefully stopt) in *Spirit of Wine*: Which I did that so I might have them in readinesse, to make on them, at any time, the Observations, I thought them capable of affording; and to let my Friends at other seasons of the year, see, *both* the differing appearances of the Chick at the third, fourth, seventh, fourteenth, or other days. . . . When the *Faetus's,* I took out, were so perfectly formed as they were wont to be about the seventh day, and after, they so well retain'd their shape and bulk, as to make me not regret of my curiosity: And some of those, which I did very early this Spring, I can yet shew you.

Scientific societies played a most important role in the advance of science. The first was the Royal Society of London, formed in 1662 for "The Improvement of Natural Knowledge" (SAAWOK—III, pp. 608–609). It has lasted to this day and has had a long and honourable history. In its early years it served as a center for scientific communication for all of Western Europe. Scientific societies play an essential role in communication through their lectures, opportunities for informal discussion among the members, and publications. Nearly all have periodicals for the shorter communications and some have monographic series for more extensive scientific contributions.

Doing science in the 16th and 17th centuries called for great courage as well as a disciplined and open mind. The Church, never a supporter of open minds, had a fixed position on many matters in the domain of natural phenomena. Generations of Catholic scholars had studied the Bible, the available works of Greek philosophers and scientists, and the writings of the Fathers of the Church and on these had built a system of thought that became Church dogma—the official and sole system of permitted thought.

And one challenged that authority at great risk. The Church had declared the Ptolemaic theory correct because, among other things, it had placed the earth at the very center of the universe. That was the proper position for one of God's main Creations. Copernicus knew the risk he was taking by demoting the earth to the position of a minor planet and, being cautious, he dedicated *De Revolutionibus* to the Pope, indicating that his view was "just a theory," and died (of natural causes) very shortly after the book was published. Others were not so lucky. Giordano Bruno, a Dominican monk, who argued for the Copernican system as well as for free thought in general, was tried by the Inquisition, imprisoned, and burned at the stake in 1600.

The Church had also decided that Galen was to have the last word when it came to anatomy and physiology. One brave, free spirit suffered in part because of that. Michael Servetus (1511–1553) was a scholar of broad interests, mainly theological, but he also was an authority on Galen. In the course of his studies, he came to the conclusion that Galen was not correct in all matters. Servetus hypothesized, for example, that blood does not pass directly through those Galenic pores from right ventricle to the left but instead goes from the right ventricle to the lungs, where it picks up air, and then back to the left ventricle. Mainly because he questioned theological dogma but partly because he questioned Galen, he aroused the suspicions of the Church. He was captured while at prayer and, after a brief trial, was sent up in flames on the 27th of October 1553. Lest the reason be in doubt, one of his offending books was hung from his neck so it too was consumed on the pyre (Fishman and Richards, 1964, pp. 18–25).

The Church was imprisoned by its own dogma. It had selected the best available scientific data before Copernicus and Vesalius and in that sense it was as up to date and as correct as it could be. However, theories and data that become dogma are not easily changed by better data that suggest new theories.

Copernicus and Vesalius

Copernicus and Vesalius were living at a time when science was becoming an established aspect of society. There were better opportunities for communication, discussion, debate, and support for one another, in spite of the fact that such activities might be heresy.

The contributions of Copernicus and Vesalius differed fundamentally. This is a reflection both of the conceptual level of astronomy and biology of the 16th century as well as of the relative degree of complexity of the two fields.

Copernicus was responsible for a true paradigm shift. By putting the sun in the center of the solar system, with the planets revolving around it, he laid the groundwork for modern astronomy. The previous paradigm had been that of Ptolemy (2nd century A.D.) who, working in Alexandria, synthesized Greek astronomy. The Ptolemaic system placed a spherical and stationary earth in the center and had the sun, moon, planets, and "fixed stars" revolving around it in circular orbits.

Vesalius was born in Brussels on New Year's Eve of 1514. He studied Galenic anatomy at Paris and then returned to Louvain, where he reintroduced the practice of human dissections. Later he went to the University of Padua, spent two days taking examinations, and was awarded a medical degree *magna cum laude.* The following day he was appointed to lecture on surgery and anatomy at this most famous of all medical schools. This must be a record for academic promotion. Vesalius departed from tradition by conducting the dissections himself (Figs. 19, 20). Usually the teacher of anatomy read from his lecture notes, which were based on Galen's writings, while an assistant pointed out the anatomical parts being mentioned.

In contrast with Copernicus, Vesalius was not responsible for a paradigm shift. Nevertheless, his contributions to anatomy were epoch making. He corrected ancient errors and provided detailed descriptions of human anatomy. Galen was the foundation of all knowledge for the anatomists of the early 16th century. Vesalius was a careful student of Galen but, as his experience with human dissections grew, he became convinced that there were many errors in Galen's descriptions—and he knew the basic reason for these errors. Galen probably had never made a systematic and detailed dissection of the human body he was describing in such detail. That would have been forbidden when he lived and what he had to say about human anatomy was based in part on the earlier work of Herophilus, who did dissect human beings, plus his own dissections of apes and other mammals. Vesalius was able to work extensively on human bodies and came to realize that some of the things reported for human anatomy by Galen were really the anatomy of apes.

Because of Vesalius, knowledge of the human body became much more accurate. *De Humani Corporis Fabrica* is a huge, beautiful book. Most noteworthy are the splendid woodcuts, which convey information about structure in ways the written word never can. The artists appear to have been students working in Titian's studio (and probably not only Jan van Calcar as suggested in SAAWOK—IV, p. 437). A sampling of these illustrations is shown in Figures 21–31.

It is often believed that after Vesalius there was little to be discovered about human anatomy. This is most certainly not the case—discoveries continue to this day but it must be admitted that no major organs have turned up recently. Vesalius was able to start with what was known of human anatomy, correct some of the errors, and add new material of his own. One of his greatest contributions was personally to make the observations and to reach conclusions based on what he saw, not the received authority of Galen. He also maintained that students should learn anatomy by doing their own dissections and, to help them, some directions are to be found in *De Humani Corporis Fabrica* and others in a dissection manual he prepared.

In many instances Vesalius continued to rely on Galen. He agreed that blood was made in the liver and that nerves were hollow. His illustration of "human" arteries seem to be based in part on Galen's apes. He failed to find any pores in the interventricular septum and marvelled at the Creator for making it possible for blood to sweat from one side to the other.


ANDREAE VESALII
BRVXELLENSIS, SCHOLAE
medicorum Patauinæ profeſſoris, de
Humani corporis ſabrica
Libri ſeptem.
CVM CAESAREAE

Apparently Vesalius was able to dissect dozens of human bodies, so one might ask, why did he leave so much unknown. Part of the answer is the extreme complexity of the human body. Another is that he worked at a magnification of 1 ×—many problems of structure and function had to await the invention of microscopes and the realization that the basic functional units of structure and function are cells (the date of Hooke's *Micrographia* is 1665).

The answer also lies in the extreme difficulty of adding a large amount of new information at one time. Even major scientific discoveries usually add but little to what is already known. For example, Copernicus made no important new discoveries—he supplied a radically different way of looking at existing data. It has taken many generations of anatomists to gain our present understanding of the human body.

It is important to note that, once knowledge of the anatomy of one species reaches a high level of accuracy and completeness, far less time is needed to acquire equal understanding of a different species. Today a competent human anatomist could quickly provide an acceptable study of another primate species and, with slightly more difficulty, that of any other mammal.

Vesalius was severely criticized by many anatomists who continued to accept the Galenic tradition, but he soon had followers, especially among the younger anatomists. After the publication of his masterpiece, his anatomical studies were few and he became a practicing physician. For him the effective medical tools were diets, drugs, and surgery. Knowledge of anatomy was basic for the last. Apparently he was an outstanding physician and for many years he served Emperor Charles V.

Vesalius's contributions were the production of a vastly improved human anatomy, an insistance on the importance of

ANDREAE VESALII.

FIG. 20. Portrait of Vesalius. Compare with Figure 19.

personal observations, and the willingness to question authority when such might be poor for one's health—or even life threatening.

As noted earlier, Vesalius made no major conceptual breakthrough. However, he did far better the sorts of things his predecessors had done and those who provide better data are of great importance for the advancement of science. For example, one of the greatest concepts in medicine is the "germ" theory of disease, meaning that the causative agent is an organism that infects a person. That theory never cured a living soul. Its importance is that it pointed a way to make new observations and to

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FIG. 19. *De Humani Corporis Fabrica* of Vesalius. Figures 19–31 reproduce many of the wood block illustrations from this book. Figure 19 is the frontispiece showing Vesalius dissecting a human cadaver. A skeleton hangs above, for reference. The demonstration is well attended. Note the instruments on the table and the single candle holder.