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The Origin of Science: Ancient Greece

Around the ninth century B.C., while J¹ and J² were trying to reunite the Hebrews, a new culture, as important to us as that of the Hebrews, arose in the eastern Mediterranean. Fortunately we are not required to trace the migrations of the Achaeans, Ionians, Dorians, and Aeolians southward, over the Greek peninsula and the neighboring shores and islands. (See Fig. 1 in previous chapter.) Let us only note that by the sixth century B.C. they were aware of themselves as Hellenes, sharing a common language, religion, and form of government, but with many local variations.

The language was Greek, of course. That the Greeks spoke Greek was fortunate for two reasons. Unlike many ancient languages Greek has written vowels, which encourages literacy. (In contrast, Hebrew had no vowel symbols until the seventh century A.D. Even if you were familiar with the spoken word Yahweh, would you recognize JHVH?) Secondly, Greek is rich in nuance, largely because its alphabet is not ideogrammatic. That is, words are not patterned after the objects they represent, as in Egyptian hieroglyphs or Chinese. Thus it is easier to get away from concrete thoughts, to create new meanings. Perhaps for that reason the early Greek scientists often wrote in verse. On the other hand, Greek scientists were handicapped by a number system which had no zero and which used the letters of the alphabet to represent numbers. This was certainly more confusing than the system we borrowed from the Arabs (which they borrowed from India); perhaps it was as bad as Roman numerals. The operation $\sigma - \kappa \epsilon = \mu \epsilon$ is no easier for us than $LXX - XXV = VL$.

The religion of Greece centered around a vast pantheon. The closest comparison we can make today is to a government bureaucracy, with the important difference that only a few bureaucrats now try to manage nature as the Greek gods and goddesses did. Zeus, the chief god, looked after the sky; Poseidon had responsibility for the sea; Hephaestus was in charge of fire, and so on. There were enough gods to go around for every town and for each household. Homer, in the *Iliad* and the *Odyssey*, relates time and again how the fates of men became entangled with the schemes of the gods. On the

other hand, the fates of the gods also depended on man: when Athens was attacked, Athena was literally threatened.

Government in Greece was centered around the city-state—the *polis*. The polis consisted of a town and its environs, with a population of no more than several thousand. This political fragmentation was dictated by the geographic fragmentation imposed by mountains and sea. This arrangement contributed to the greatness of Greece, but also made that greatness short-lived. Jealousy among competing poleis made wars inevitable (for example the Peloponnesian War) and often prevented alliances against outside invaders such as the Macedonians. But in intervals of peace the competition could be healthy. The small size of each city-state dictated that it had to import many goods, and along with them many ideas. The small population made it possible for each citizen to participate knowledgeably in public affairs. Thus was born democracy; an ideal of the polis which we try to apply to the metropolis and megalopolis.¹

All the Greeks had much the same language, religion, and government, but in the sixth century B.C. something peculiar to the shores of Ionia (present-day Turkey) gave rise to a new and bizarre notion. A number of Ionians became obsessed with the heresy that nature is not simply a whim of the gods, but that natural phenomena consistently follow particular causes which men can understand. There is no record of the idea prior to that time, and mankind was apparently cured of the fixation afterward, until it broke out again in the European Renaissance. Now, of course, this epidemic of science has infected us all.²

THE PRE-SOCRATIC PHILOSOPHER-SCIENTISTS

The first known scientist was Thales, who flourished around 600 B.C. Augustine (*City of God* VIII. 2) says Thales was an author, but nothing of his has survived. As with many early scientists, all we know of him is what Aristotle, Herodotus, Diogenes Laertius, and others said, often centuries later. There is evidence that Thales travelled to Egypt and returned with geometry. In the hands of the Greeks geometry became much more than the surveying tricks of the Egyptians. (Geometry literally means "earth-measurement.") Pythagoras, particularly, was to be impressed with the idea that the gods were geometers, if, indeed, they were not numbers. In addition to introducing geometry, Thales may also have been the first to pose a question which was to preoccupy all of the Greek philosopher-scientists: What is the primary element of which all things are made? It is not surprising that a resident of the chief Greek seaport (Miletus) decided that water must be the primary element. (See Burnet, 1957, pp. 40–50.) Thales would undoubtedly be amused by our physicists' search for quarks.

Anaximander (flourished around 580 B.C. was also a resident of Miletus and may have learned science directly from Thales. He is of interest to us here because of his speculation on the origin of man, which has sometimes been interpreted as evolutionary. Anaximander's reputation as an evolutionist rests on the following opinions attributed to him by other ancients:³

1. Living creatures arose from the moist element as it was evaporated by the sea. Man was like another animal, namely a fish, in the beginning.
2. Further, he [Anaximander] says that originally man was born from animals of another species. His reason is that while other animals quickly find food by themselves, man alone required a lengthy period of suckling. Hence, had he been originally as he is now, he would never have survived.
3. He [Anaximander] declares that at first human beings arose in the insides of fishes, and after having been reared like sharks, and become capable of protecting themselves, they were finally cast ashore and took to land.

Thus, Anaximander suggests that man originated from a previous species, namely a fish. But if this is considered evolution, then the honor of being the first evolutionist must surely go to the nameless primitive who first spun a tale of one species being transformed into another. Far from proving that Anaximander was an evolutionist, these quotations prove that he was not. The problem he wished to solve was how the first human, as an infant without human parents, could have survived. That problem would not occur to an evolutionist, because the first human would have had parents similar enough to him to provide nourishment. Clearly Anaximander believed that the first human arose suddenly (from the sea, naturally), not by gradual evolution.

Although Anaximander does not deserve the title of First Evolutionist, he should be credited with an equally important innovation. That is the notion that naked reason is better than ignorance cloaked in priestly garb. Even on the touchy question of the origin of man he did not resort to a supernatural explanation, but attempted to apply his understanding of present causes to past phenomena. In short, Anaximander was the first to suggest a scientific explanation for the origin of a species.

Of the other Ionian philosopher-scientists we need say little since they left no writings pertaining to the origin of species. They interest us primarily as carriers of science to Athens and to other areas of Hellas following the subjugation of Ionia by Persia, which began in 546 B.C. under Cyrus.⁴ Let us leave Ionia, as the Ionians did.

We skip a hundred years and a thousand kilometers to Sicily. In that time and place lived Empedocles, who, like Anaximander, is sometimes said to have been an evolutionist. Empedocles was something of a character; were he alive today he would have to be either a rock star or a resident of a back ward of a mental institution. He was a powerful aristocrat who claimed to

have been a god in a previous life, and dressed accordingly in bronze sandals and purple robes. He was a faith healer and evangelist for his own religion. He must also have had a dual personality, for he is said to have declined a dictatorship in order to lead a simple life. Aristotle credited him with the invention of rhetoric, and Cicero praised his poetry. Empedocles is said to have died in the crater of Aetna.³

Of the 2,000 verses which Empedocles wrote *On Nature*, only a few fragments survive. The case for Empedocles as an evolutionist is based on six of them (see selections in this chapter), plus a few comments by Aristotle. According to this evidence Empedocles taught that the two great forces of nature were Love (or Friendship) and Hate (Strife).⁴ During a "reign of Love" parts of animals arose from the Earth through the attraction of the four elements (fire, air, earth, and water), and these parts combined randomly with each other. A large number of monsters, such as cattle with human faces, would have been produced in this way. According to Aristotle (*Physics* II. 8), Empedocles said these monsters would not have survived. However, a few lucky individuals with the correct number and arrangement of parts would have survived, and these were the originals of the species alive now. Clearly this is not the evolution of one species from another.

Empedocles' unearned reputation as an evolutionist is largely due to his clear statement of the survival of the fittest in the citation by Aristotle. Empedocles seems to have been the first to appreciate the constructive power inherent in the elimination of the unfit. But we must remember the difference between natural selection as a cause of evolution and evolution itself. Empedocles knew the answer to what causes evolution, but he did not know the question.

Meanwhile the Persians were attempting to spread their empire into the Greek peninsula. To meet this threat Athens formed an alliance in 477 B.C. in which it provided ships and troops for the defense of other city-states for a price. Following the defeat of the Persians in 468, this arrangement continued. (Some of the allies attempted to break away, but were made offers by Athens which they could not refuse.) In effect there was an Athenian Empire. With a strong fleet to enforce peace and promote trade, money flowed into Athens. For the brief period of 463 to 431, under the democracy of Pericles, Athens enjoyed a Golden Age which is still the envy of Western man. Dramatists, sculptors, and philosophers were attracted from all over Hellas by the patronage of Pericles. Grand as its achievements were, however, Athens was still a small town, and its citizens had that smallness of spirit which periodically prunes off those who grow too far above the ordinary. Anaxagoras had to flee after suggesting that the sun was not a god but only a ball of fire. Pericles himself was pulled down, charged with starting war, squandering public funds on arts and science, and turning his home into a brothel. And gentle Socrates paid with his life for allegedly "refusing to

recognize the gods recognized by the state . . . introducing new divinities [and] corrupting the youth."

This was not a golden age for science. For more than a century after Thales, philosopher-scientists had explored nearly every combination of primary elements, ideal geometry, and the other obsessions of the pre-Socratics. Then the Eleatics added a new twist: all was one and unchanging. Thus motion was an illusion, and one could not rely upon the senses. Although the Eleatics respected reason, the paradoxes they used in their arguments made others doubt it. Then came the Sophists, who argued that one can never know anything except the real. They doubted the power of abstract reasoning and made a mockery of it by their ability to defend any side of an argument. With the Eleatics arguing that things are not what they seem, and the Sophists arguing that things are *only* what they seem, science was undermined as its very foundation. With either philosophy one must doubt man's ability to understand the causes of natural phenomena.⁵

In addition, political conditions following the Golden Age were unfavorable to science. From 431 to 404 Athens and Sparta seemed bent on suicide in the Peloponnesian War. That war had no definite conclusion, but ended largely because the forests which had covered Greece were stripped (to this day), and no more warships could be built. In Athens, during the last year of the war, democracy was interrupted by a violent Tyranny of the Thirty. In such times of grave problems the claim that science is an unaffordable luxury must have been as familiar to the Athenians as it is to us. (When have there not been grave problems?) Without advanced technology, supporters of science could not even claim that knowledge of the atom and such might end war or otherwise materially benefit mankind. Thus, as Aristotle notes, "in Socrates' time . . . philosophers gave up the study of Nature and turned to the practical subject of 'goodness' and to political science."

SOCRATES (469–399)

Socrates turned away from science to contemplate his soul. This is reflected in his disregard for appearance and money, and in his patient bearing of abuse from his wife Xanthippe.⁶ For Socrates the important questions related to absolute equality, beauty, goodness, justice, and holiness. The answers were not to be found in nature, but within one's self. Many pre-Socratics had tried to explain human behavior on the basis of the behavior of the elements—not even distinguishing among body, mind, and soul—but Socrates saw no value in this approach. While waiting to drink the fatal hemlock he explains to his pupils that there must be an immortal, nonmaterial soul directing his body: "for I am inclined to think that these muscles and bones of mine would have gone off long ago to Megara or

Boeotia—by the dog, they would, if they had been moved only by their own idea of what was best. . . .”¹⁰ The soul, he maintained, exists fully formed from birth, and learning is but remembering what the soul has always known. This innate knowledge could be drawn out by the method of dialectic—the Socratic method of asking questions which lead to an inevitable conclusion. For Socrates the soul was primary and eternal. Since the body was only its temporary vessel, he showed little interest in how it originated.

PLATO (428–348)

From age twenty Plato was torn between the philosophy of Socrates and a career in politics. His family was one of the most influential of Athens (like many aristocrats, his father traced his ancestry to a god), and Plato's achievements in music, mathematics, rhetoric, poetry, wrestling, and warfare would have made him a formidable candidate. The mantle of Pericles would have rested easily on his broad shoulders, but it was no longer the Golden Age. For the first twenty-four years of Plato's life Athens was entangled in the Peloponnesian War, and then Plato's own relatives plotted the Tyranny of the Thirty. Plato was offered a share of the spoils of the Thirty, but he declined because of their violence and schemes against Socrates. Democracy was soon restored, but the condemnation of Socrates convinced Plato that he had no future in governing such people as the Athenians. (Ironically, an older Plato decided that imprisonment and death were appropriate sentences for heretics. See his *Laws*, Book X.)

Following the execution of Socrates, Plato made a tour of the Mediterranean. We can imagine him wandering dejectedly, much of his family and his beloved teacher now dead. Perhaps it was then that Plato made plans to carry on the teachings of Socrates, and if unable actually to rule, at least to advise others how to. He visited Italy and Sicily, where he found the political turmoil and “laborious prosecution of debauchery” repulsive. He attempted, with some personal risk, to deter the rulers of Syracuse from despotism. Upon returning to Athens in 387 Plato founded his Academy, which survived as a leading university of Greece for nine centuries.¹¹

Like Socrates, Plato was primarily interested in absolute goodness and abstract principles underlying reality. As he explained in the famous parable of the cave (*Republic* VII), what we perceive as reality is like a shadow of the absolute. Real chairs, triangles, and animals are only imperfect copies of perfect abstractions. Plato believed that studying these imperfect copies could only lead to imperfect knowledge, just as studying real triangles can only result in inaccurate geometry. In fact, Plato took geometry as the model for all reasoning. Above the door of the Academy was inscribed “Let no one without geometry enter here.” Plato hoped that the same reasoning which

allowed one to imagine a tangent touching a circle at only one infinitesimal point would also allow one to contemplate the absolute. Undoubtedly Plato was still somewhat under the spell of the Pythagoreans, who had made mathematics a religion encompassing music, art, and astronomy. Socrates, in contrast, had considered mathematics as only a useful technique of measurement.

Plato's one scientific dialogue (actually more of a monologue) is put into the mouth of Timaeus; it is not clear whether all the views expressed are Plato's. Perhaps he intended it to be that way to avoid charges of impiety. Timaeus describes how the creator, a god not otherwise identified, made the world out of chaos by shaping the four elements, using the abstract ideal universe as a model. The creator then made the lesser gods (which correspond to the element fire), and delegated to them the task of creating birds (corresponding to air), aquatic animals (water), and terrestrial animals (earth). These gods first created men (male humans), who were, naturally, flawed copies of the ideal of the species. The body was composed of tiny triangles, which, as their corners begin to wear down, fit increasingly badly, resulting in disease and aging. Timaeus says there are three types of soul in man: The highest resides in the head and is unique to man. A second soul is the source of courage; it resides in the chest and is shared by animals. The lowest soul is responsible for maintaining life; it resides in the abdomen and is shared even by plants. Men could live well or badly, according to which soul was dominant.

Women and other species of animals arose through reincarnation. When a man died the soul of him “who lived well during his appointed time was to return and dwell in his native star, . . . but if he failed in attaining this, at the second birth he would pass into a woman . . . and if . . . he did not desist from evil, he would continually be changed into some brute. . . .” Women came from cowardly and unrighteous men.¹² “Flighty” men became birds. Men who never used the higher soul became terrestrial animals. The most ignorant became “fishes and oysters.” (See selection in this chapter.)

This description of the origin of species may sound just as mythical as the ones discussed in the previous chapter. (In fact, the *Timaeus* was translated into Latin in 350 A.D. because it was thought to be a religious work [C. U. M. Smith, 1976, p. 60].) Unlike Genesis, however, the *Timaeus* makes as much—or as little—sense without the gods. To the degree that physical causes and effects are invoked, it is scientific work.¹³

ARISTOTLE (384–322)

We have explored two main streams of Greek philosophy: the materialist stream of the pre-Socratics, and the idealist stream of Socrates and Plato.

Now we come to the confluence of these currents with Aristotle. As Plato's star pupil from 367 to 347, Aristotle absorbed the belief in abstract principles governing nature. Yet Aristotle's idealism was tempered by a curiosity about the real world and especially about life. Perhaps this reflected the influence of his father, who was a physician. Unlike Plato, Aristotle did not wish to make an end run around nature to get to the ideal: "For though there are animals which have no attractiveness for the senses, yet for the eye of science, for the student who is naturally of a philosophic spirit and can discern the causes of things, Nature which fashioned them provides joys which cannot be measured." (*Parts of Animals* I. 5. A. M. Peck translation.)

Aristotle's refusal to follow Plato's footsteps precisely may have created some friction between the two. For some reason Aristotle was not chosen to be Plato's successor as head of the Academy. Instead Aristotle and other former students of Plato founded their own school in the northwest of what is now Turkey. Their patron was the tyrant Hermias the eunuch, who gave a town to the school, and his adopted daughter to Aristotle. Shortly afterwards the Persians crucified Hermias for plotting with Philip II of Macedonia against them. Aristotle fled a short distance to the islands of Lesbos, where he studied marine biology, and where the death of his wife left him a widower with a daughter. Because of his connection with Hermias, and because Aristotle's father had been a physician to Philip's father, Aristotle was summoned in 343 to be one of the tutors to Philip's son, Alexander. During the time that Aristotle served in Philip's court, Philip expanded his dominion southward. Athens was absorbed in 338, but there was little disruption in the intellectual life, for Philip hoped to unite the Hellenes, not merely to subdue them. When Philip was assassinated in 336 that goal fell to Alexander, then age twenty and not yet "the Great." Aristotle returned to Athens, wealthy enough to establish his new school and confident that he would be spared the fate of Socrates as long as Alexander ruled. Aristotle's Lyceum was well equipped with the best library in Europe, maps, and a zoological garden. There, adorned in rings and bright robes, he lectured to eager and competent students. Aristotle's career at the Lyceum ended in 323 with the death of Alexander following a successful wine-drinking contest. Athenians lost no time in manifesting their hostility toward those with Macedonian ties. They charged Aristotle with impiety for composing a hymn to his father-in-law and for refusing to worship the old gods. Aristotle died within a year after fleeing. His parting words were said to have been "I will not let the Athenians offend twice against Philosophy."¹

The surviving works of Aristotle fill more than 1,400 pages of fine print (Hutchins, 1952, vols. 8, 9), and they are only the fraction left after the Goths sacked Rome (410 A.D.) and Christians burned the libraries at Alexandria (392) and Constantinople (1204). Diogenes Laertius lists more than 350 books by Aristotle! This is a bit much for one mortal, even allowing that

Alexander the Great had a thousand men collecting specimens and information for him, as Pliny claimed. Whoever made his observations showed great skill as an observer, pushing the unaided eye to its limit. Yet many of the errors in Aristotle's works, such as the belief that insects are generated spontaneously and the charming tale of salamanders putting out fires, could have been corrected by the most elementary experiments. (See selection in this chapter.) Probably many of the writings attributed to Aristotle were actually compiled by students as projects, but those students clearly took their inspiration from Aristotle, for there is remarkable coherence and lack of contradiction in the writing.

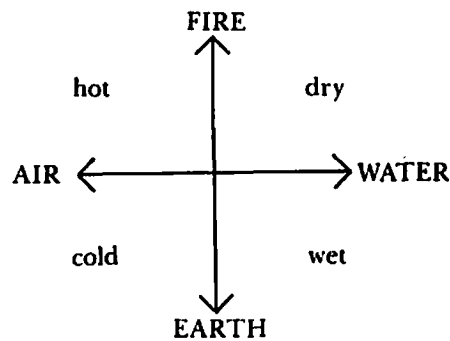
Aristotle's interests included physics, logic, meteorology, metaphysics, the soul, memory, dreams, politics, rhetoric, drama, and various aspects of biology. As we shall see in the next chapter, this encompassing breadth and unity, rediscovered so soon after the Dark Ages, would dazzle many Europeans into regarding Aristotle's work as a second Bible. So tangled are the threads uniting Aristotle's writings that one cannot question his *Metaphysics* without doubting his biology. The *Parts of Animals*, for example, is not simply a book on anatomy, but a description of the ultimate causes of life. His *History of Animals* may seem to be a collection of animal lore—from the trivial (on lice) to the weighty (copulation by elephants)—but for Aristotle this is the evidence of design and purpose in nature. Repeatedly he tells us, "Nature does nothing in vain."

Aristotle's insistence on design and purpose in nature leads to other inevitable conclusions. A problem with design (in addition to those which were discussed in the previous chapter) is that all earthly things are changing (unless the Eleatics were correct). But why should an ideally designed object change? Aristotle responded by arguing, with Plato, that real objects are imperfect, and the changes we see are their movements toward a final, perfect state. But this too presents a problem, because Aristotle was a good enough physicist to know that motion does not originate spontaneously within an object. It was therefore necessary for him to postulate an unmoved or Prime Mover, which was the source of all other motions. (See *On the Heavens*.) In the Middle Ages the Prime Mover was equated with the Judeo-Christian God, but Aristotle wrote of it only as a divine, rotating sphere surrounding the universe, with the Earth at its center.

The unmoved mover presented Aristotle with another problem. The four earthly elements which had been agreed upon by Aristotle's time were all corruptible and moved only briefly in straight lines. (See Fig. 2.)

But Aristotle knew from ancient astronomical data that the stars and planets had not departed from their apparently circular orbits, so they could not be composed of air, fire, earth, or water. He therefore proposed a fifth (quintessential) element, *ether*, whose natural motion was circular, as the material of the celestial realm. The unmoved mover transmitted its circular motion

FIGURE 2. Natural motion and qualities of the four elements. Fire is hot and dry and tends to rise; earth is cold and wet and tends to fall, etc.



through the ether, stars, and planets to the moon, which then transmitted it to the Earth and its inhabitants.

The motions induced in living and nonliving things on Earth were the result of *final causes* driving them to fulfill their destinies. Thus the final cause of the egg is the chicken. Aristotle also recognized a *material cause*; whether the egg contains more or less fire, for example, could determine the health of the chick. There were also an *efficient cause* (the hen) and a *formal cause* (the egg-ness of the egg). Another pervasive theme of Aristotle is *psyche*—what the translators have chosen to call “soul.” As explained in *On the Soul*, Aristotle regarded each living thing as a unique entity with a *psyche*, and not just a collection of atoms and organs. He expanded the number of aspects of soul from the three of *Timaeus* to five: there was a nutritive part which even plants had; the sensory, locomotive, and appetitive parts which certain animals had in addition to the nutritive part; and the intellectual part, which only humans had. The souls of modern man have been relieved of the duties assigned to the *psyche* by Aristotle. Biologists now attribute those functions to physiology.¹³

Aristotle's vision of life was very different from our evolutionary, ecological, clockwork view. He saw each organism as aspiring to the ideal of its own species, not as evolving toward some other species. To him ecological competition resulted from the less-than-perfect state of nature; to us the struggle for existence is nature. Individual organisms were moved by their psyches, which were driven by the Prime Mover; they were not simply reading the DNA script or obeying the commands of the hypothalamus. Yet Aristotle is often accused of having a modern conception of evolution. As with Anaximander and Empedocles, this error results from careless reading of what Aristotle actually said, especially in four passages.

The first passage was quoted by Darwin in a footnote in his “Historical Sketch,” which he included in later editions of *Origin of Species*. In the quotation Aristotle is actually rejecting Empedocles' idea of natural selection, but Darwin was apparently told just the opposite. Darwin's footnote reads:

Aristotle in his *Physicae Auscultationes* (*Physics*, II. 8), after remarking that rain does not fall in order to make the corn grow, any more than it falls to spoil the farmer's corn when threshed out of doors, applies the same argument to organization; and adds (as translated by Mr. Clair Grece, who first pointed out the passage to me), ‘So what hinders the different parts (of the body) from having this merely accidental relation in nature? as the teeth, for example, grow by necessity, the front ones sharp, adapted for dividing, and the grinders flat, and serving for masticating the food; since they were not made for the sake of this, but it was the result of accident. And in like manner as to the other parts in which there appears to exist an adaptation to an end. Wheresoever, therefore, all things together (that is all the parts of one whole) happened like as if they were made for the sake of something, these were preserved, having been appropriately constituted by an internal spontaneity; and whatsoever things were not thus constituted, perished, and still perish.’ We here see the principle of natural selection shadowed forth, but how little Aristotle fully comprehended the principle, is shown by his remarks on the formation of teeth.

That Aristotle was actually rejecting the idea of natural selection is seen by his words immediately following those quoted by Darwin: “. . . as Empedocles says his man-faced ox-progeny did. Such are the arguments (and others of the kind) which may cause difficulty on this point. Yet it is impossible that this should be the true view.”

The second cause of Aristotle's reputation as an evolutionist is William Ogle's translation of Aristotle's word for formation or development as “evolution.” (Aristotle's word was none other than *genesis*.) Ogle's translation reads:

The best course appears to be that we should follow the method already mentioned, and begin with the phenomena presented by each group of animals, and, when this is done, proceed afterwards to state the causes of these phenomena, and to deal with their evolution. For elsewhere, as for instance in house building, this is the true sequence. The plan of the house, or the house, has this and that form; and because it has this and that form, therefore is its construction carried out in this or that manner. For the process of evolution is for the sake of the thing finally evolved, and not this for the sake of the process. (*Parts of Animals* 1. 1)

At the time of Ogle's translation (1882) the word “evolution” was used in a general sense to mean gradual change, and in a biological sense to mean

embryonic development (Bowler, 1975; Gould, 1977, Ch. 3; T. H. Huxley, 1896, Ch. 6). Darwin himself rarely applied the term to the origin of species, and since Aristotle was apparently referring to embryonic development in this passage, Ogle's translation was justified at the time. The fault lies not with Ogle but with those who apply current meanings to old words.

Osborn (1929, p. 87) considered Aristotle an evolutionist on the basis of a passage which occurs shortly after the one quoted above by Darwin. The translation he cites reads: "Further still, it is necessary that germs should have been first produced, and not immediately animals; and that soft mass which first subsisted was the germ." In other translations, and in the context, it is clear that "germ" is the seed from which individual plants and animals arise, not the primordial cell from which all organisms evolved.

Finally, many biologists and historians (for example Nordenskiöld, 1929, p. 37, and Sarton, 1927, p. 128) have been misled by the following words: "Nature proceeds little by little from things lifeless to animal life in such a way that it is impossible to determine the exact line of demarcation, nor on which side thereof an intermediate form should lie" (*History of Animals* VIII. 1. D'Arcy Wentworth Thompson translation).¹⁶ The troublesome word here is "proceeds," which implies progression in time. From the rest of the paragraph, however, it is clear that Aristotle is noting the difficulty of distinguishing between similar species. This was a remarkable observation in itself, but hardly sufficient to infer evolution.

So what were Aristotle's views on the origin of species? In the first place he was not quite sure they had an origin, but if they did it would have been no different from the origin of individuals through embryonic development.

Hence one might suppose, in connection with the origin of men and quadrupeds, that if they were really "earth-born" as some say, they came into being in one of two ways; that either it was by the formation of a scolex (larva) at first or else it was out of eggs. . . . It is plain then, that, if there really was any such beginning of the generation of all animals, it is reasonable to suppose it to have been one of these two, scolex or egg. (*Generation of Animals* III. 11. A. Platt translation)

In the case of certain invertebrates, eels, and certain fish Aristotle is more confident—they arose and still arise spontaneously from filth. Intestinal worms and flies are generated in feces, some fish and eels come from mud and sand, and so on. (See the selection in this chapter and *History of Animals* VI. 15, 16.) The idea of spontaneous generation did not originate with Aristotle; nor did it die with him. It took twenty centuries for a Francesco Redi to do the experiments, which Aristotle could easily have done, to disprove spontaneous generation of insects. The idea of spontaneous generation, in fact, survived until Pasteur's experiments little more than a century ago (Farley, 1977).

EPICURUS (342?–270)

Science did not die with Aristotle; the work of his student, Theophrastus, in botany rivaled that of Aristotle in zoology, and the achievements of Euclid and Archimedes are still admired. But the best science was no longer done in Athens, but in Alexandria. Alexander had founded this city in 332, and its Museum and Library were the center for knowledge for many years under the first few Ptolemys. Alexander's conquest of Persia and his completion of Hellenization from India to Egypt broke down linguistic and political barriers to the spread of science. Alexander's impact can be judged from the fact that Jewish scholars had to have the Pentateuch translated into Greek in order to read it. (This is why our oldest biblical text, the Septuagint, is in Greek, and why the first book of the Bible has a Greek title.) Scholars, physicians, priests, philosophers, and scientists were drawn to Alexandria as they had once been to Athens. Imagine the lunch-time conversation with Euclid the geometer, and perhaps a priest from Jerusalem, a Persian sage, and a student from the Lyceum. Oh, for a time machine and a tape recorder! By law any new books brought into Alexandria had to be submitted for translation and publication by the Library. Eventually the Library accumulated hundreds of thousands of books. This was a major feat considering that books were hand-copied on long rolls of papyrus. Such scrolls were expensive and scarce, and only the best writings would have been worth the effort. How different from our inexpensive books which can be turned out virtually overnight—and forgotten just as quickly.¹⁷

As the center of learning migrated to Alexandria, Athenians seem to have sought consolation from the Cynics, Skeptics, Stoics, and Epicureans. Only the Epicureans concern us here, because Epicurus apparently expounded on the origin of species. None of his writings on the subject remains, but his other views were so faithfully plagiarized by Lucretius that we can assume the same for his ideas on origins. We may thus postpone a discussion of them until we get to Lucretius, but it is of present interest to learn the circumstances which led Epicurus to such speculations. Epicurus was apparently as impressed by the social and political chaos of the times as Aristotle was by the orderliness of nature. He saw in the randomly moving atoms proposed by Democritus (460?–362?) a picture in miniature of the state of the world.¹⁸ Epicurus modified Democritus's ideas by postulating that atoms occasionally swerve spontaneously, thus giving rise to man's free will. This swerve allowed Epicurus to dispense with Aristotle's Prime Mover, with its attention concentrated on Earth. As far as Epicurus was concerned, the gods did not bother about the problems of man, so there was no reason for men to. The Earth and its troubles vanish in infinite space. Though under a sentence of death, all men may find tranquility in contemplating the benign indifference of the universe.¹⁹

LUCRETII (99?–55?)

While Athens was in its senescence, Rome was in the throes of labor, giving birth to a new empire. Its victory over Carthage in the Punic Wars (264–146) had left Rome virtually unopposed in its control over the Mediterranean. Macedonia, then only a fragment of Alexander's empire, tried but failed to organize resistance. Many Greeks first welcomed Roman conquest in 197 as being at least a change from the Macedonians. They later had reason to change their minds after witnessing Roman methods for dealing with Greek desires for independence. Rome continued its expansion into Europe under Julius Caesar (100–44), but at the same time that Rome was demonstrating its ability to rule others, it seemed unable to rule itself. Although nominally a republic since 509 B. C., Rome became essentially an anarchy by the first century B. C., following a series of civil wars, revolts, and reigns of terror. The revolt of Spartacus (73 B. C.) and the crucifixion of 6,000 of his followers give some idea of those brutal times. Finally, in 49, Caesar crossed the Rubicon, captured Rome, and restored order at the price of liberty. The rest of Rome's history will wait until the next chapter.

Titus Lucretius Carus had the misfortune to live during the terrible times leading up to Caesar's dictatorship. Little is known about him, possibly because of the deliberate policy of suppressing Epicurean writings under the Caesars and later emperors. Rome wanted its subjects to believe that the gods were on their side; Lucretius dared to suggest that the gods did not even notice our little planet, much less worry over who was trying to conquer it. The one semblance of a fact regarding Lucretius is the doubtful statement by Saint Jerome, writing four centuries afterwards, that Lucretius went insane from an aphrodisiac and eventually killed himself. Perhaps Lucretius did seek peace in the arms of Venus, as he sought it in the writings of Epicurus. Like many Roman artists and philosophers of the time, Lucretius was not especially original, but he displayed excellent judgment in choosing what to copy. Parts of his poem *De Rerum Natura* (*On the Nature of Things*) are quite similar to letters by Epicurus explaining his philosophy. (For these letters see Diogenes Laertius, 1950, vol. 2, pp. 565–659.) Although Lucretius was himself an elegant poet, the idea of writing in verse may have been borrowed from Empedocles. Empedocles may also have been the source of Lucretius's ideas on natural selection, which appear in the last selection of this chapter. The major difference between Empedocles and Lucretius is that the latter has the Earth bringing forth entire organisms, not just parts. According to Lucretius, men originated from wombs attached to trees! This and other of Lucretius's ideas may seem fanciful, but his motive was clearly to dispel religious superstitions by proposing natural explanations for the origin of species and other phenomena. In that sense, he was a scientific writer.²⁰

Empedocles: Six fragments. From K. Freeman, *Ancilla to the Pre-Socratic Philosophers*. Harvard University Press, Cambridge, 1956, pp. 58, 59. By permission.

57. On it (*Earth*) many foreheads without necks sprang forth, and arms wandered unattached, bereft of shoulders, and eyes strayed about alone, needing brows.

58. Limbs wandered alone.

59. But as the one divinity became more and more mingled with the other (*i. e. Love and Hate*), these things fell together as each chanced, and many other things in addition to these were continuously produced.

60. Creatures with rolling gait and innumerable hands.

61. Many creatures were created with a face and breast on both sides; offspring of cattle with the fronts of men, and again there arose offspring of men with heads of cattle; and (*creatures made of elements*) mixed in part from men, in part of female sex, furnished with hairy limbs.

62. Come now, hear how the Fire as it was separated sent up the night-produced shoots of men and much-lamenting women; for my tale is not wide of the mark nor ill-informed. At first, undifferentiated shapes of earth arose, having a share of both elements Water and Heat. These the Fire sent up, wishing to reach its like, but they did not yet exhibit a lovely body with limbs, nor the voice and organ such as is proper to men.

Selection from Plato, *Timaeus*. Translated by B. Jowett.

Thus our original design of discoursing about the universe down to the creation of man is nearly completed. A brief mention may be made of the generation of other animals, so far as the subject admits of brevity; in this manner our argument will best attain a due proportion. On the subject of animals, then, the following remarks may be offered. Of the men who came into the world, those who were cowards or led unrighteous lives may with reason be supposed to have changed into the nature of women in the second generation. And this was the reason why at that time the gods created in us the desire of sexual intercourse, contriving in man one animated substance, and in woman another, which they formed respectively in the following manner. The outlet for drink by which liquids pass through the lung under the kidneys and into the bladder, which receives and then by the pressure

of the air emits them, was so fashioned by them as to penetrate also into the body of the marrow, which passes from the head along the neck and through the back, and which in the preceding discourse we have named the seed. And the seed having life, and becoming endowed with respiration, produces in that part in which it respire a lively desire of emission, and thus creates in us the love of procreation. Wherefore also in men the organ of generation becoming rebellious and masterful, like an animal disobedient to reason, and maddened with the sting of lust, seeks to gain absolute sway; and the same is the case with the so-called womb or matrix of women; the animal within them is desirous of procreating children, and when remaining unfruitful long beyond its proper time, gets discontented and angry, and wandering in every direction through the body, closes up the passages of the breath, and, by obstructing respiration, drives them to extremity, causing all varieties of disease, until at length the desire and love of the man and the woman, bringing them together and as it were plucking the fruit from the tree, sow in the womb, as in a field, animals unseen by reason of their smallness and without form; these again are separated and matured within; they are then finally brought out into the light, and thus the generation of animals is completed.

Thus were created women and the female sex in general. But the race of birds was created out of innocent light-minded men, who, although their minds were directed toward heaven, imagined, in their simplicity, that the clearest demonstration of the things above was to be obtained by sight; these were remodelled and transformed into birds, and they grew feathers instead of hair. The race of wild pedestrian animals, again, came from those who had no philosophy in any of their thoughts, and never considered at all about the nature of the heavens, because they had ceased to use the courses of the head, but followed the guidance of those parts of the soul which are in the breast. In consequence of these habits of theirs they had their front-legs and their heads resting upon the earth to which they were drawn by natural affinity; and the crowns of their heads were elongated and of all sorts of shapes, into which the courses of the soul were crushed by reason of disuse. And this was the reason why they were created quadrupeds and polypods: God gave the more senseless of them the more support that they might be more attracted to the earth. And the most foolish of them, who trail their bodies entirely upon the ground and have no longer any need of feet, he made without feet to crawl upon the earth. The fourth class were the inhabitants of the water: these were made out of the most entirely senseless and ignorant of all, whom the transformers did not think any longer worthy of

pure respiration, because they possessed a soul which was made impure by all sorts of transgression; and instead of the subtle and pure medium of air, they gave them the deep and muddy sea to be their element of respiration; and hence arose the race of fishes and oysters, and other aquatic animals, which have received the most remote habitations as a punishment of their outlandish ignorance. These are the laws by which animals pass into one another, now, as ever, changing as they lose or gain wisdom and folly.

Aristotle, History of Animals, Book V, Chapter 19. Translated by D. W. Thompson

With regard to insects, that the male is less than the female and that he mounts upon her back, and how he performs the act of copulation and the circumstance that he gives over reluctantly, all this has already been set forth, in most cases of insect copulation this process is speedily followed up by parturition.

All insects engender grubs, with the exception of a species of butterfly; and the female of this species lays a hard egg, resembling the seed of the cneus, with a juice inside it. But from the grub, the young animal does not grow out of a mere portion of it, as a young animal grows from a portion only of an egg, but the grub entire grows and the animal becomes differentiated out of it.

And of insects some are derived from insect congeners, as the venom-spider and the common-spider from the venom-spider and the common-spider, and so with the attelabus or locust, the acris or grasshopper, and the tettix or cicada. Other insects are not derived from living parentage, but are generated spontaneously: some out of dew falling on leaves, ordinarily in spring-time, but not seldom in winter when there has been a stretch of fair weather and southerly winds; others grow in decaying mud or dung; others in timber, green or dry; some in the hair of animals; some in the flesh of animals; some in excrements: and some from excrement after it has been voided, and some from excrement yet within the living animal, like the helminthes or intestinal worms. And of these intestinal worms there are three species: one named the flat-worm, another the round worm, and the third the ascarid. These intestinal worms do not in any case propagate their kind. The flat-worm, however, in an exceptional way, clings fast to the gut, and lays a thing like a melon-seed, by observing which indication the physician concludes that his patient is troubled with the worm.

The so-called psyche or butterfly is generated from caterpillars which grow on green leaves, chiefly leaves of the raphanus, which some call crambe or cabbage. At first it is less than a grain of millet; it then grows into a small grub; and in three days it is a tiny caterpillar. After this it grows on and on, and becomes quiescent and changes its shape, and is now called a chrysalis. The outer shell is hard, and the chrysalis moves if you touch it. It attaches itself by cobweb-like filaments, and is unfurnished with mouth or any other apparent organ. After a little while the outer covering bursts asunder, and out flies the winged creature that we call the psyche or butterfly. At first, when it is a caterpillar, it feeds and ejects excrement; but when it turns into the chrysalis it neither feeds nor ejects excrement.

The same remarks are applicable to all such insects as are developed out of the grub, both such grubs as are derived from the copulation of living animals and such as are generated without copulation on the part of parents. For the grub of the bee, the anthrena, and the wasp, whilst it is young, takes food and voids excrement; but when it has passed from the grub shape to its defined form and become what is termed a "nympha", it ceases to take food and to void excrement, and remains tightly wrapped up and motionless until it has reached its full size, when it breaks the formation with which the cell is closed, and issues forth. The insects named the hypera and the penia are derived from similar caterpillars, which move in an undulatory way, progressing with one part and then pulling up the hinder parts by a bend of the body. The developed insect in each case takes its peculiar colour from the parent caterpillar.

From one particular large grub, which has as it were horns, and in other respects differs from grubs in general, there comes, by a metamorphosis of the grub, first a caterpillar, then the cocoon, then the *necydalus*; and the creature passes through all these transformations within six months. A class of women unwind and reel off the cocoons of these creatures, and afterwards weave a fabric with the threads thus unwound; a Coan woman of the name of Pamphila, daughter of Plateus, being credited with the first invention of the fabric. After the same fashion the carabus or stag-beetle comes from the grubs that live in dry wood: at first the grub is motionless, but after a while the shell bursts and the stag-beetle issues forth.

From the cabbage is engendered the cabbage-worm, and from the leek the *prasocuris* or leekbane; this creature is also winged. From the flat animalcule that skims over the surface of rivers comes the oestrus or gadfly; and this accounts for the fact that gadflies most abound in the neighbourhood of waters on whose surface these animalcules are

observed. From a certain small, black and hairy caterpillar comes first a wingless glow-worm; and this creature again suffers a metamorphosis, and transforms into a winged insect named the bostrychus (or hair-curl).

Gnats grow from ascarids; and ascarids are engendered in the slime of wells, or in the places where there is a deposit left by the draining off of water. This slime decays, and first turns white, then black, and finally blood-red; and at this stage there originate in it, as it were, little tiny bits of red weed, which at first wriggle about all clinging together, and finally break loose and swim in the water, and are hereupon known as ascarids. After a few days they stand straight up on the water motionless and hard, and by and by the husk breaks off and the gnat is seen sitting upon it, until the sun's heat or a puff of wind sets them in motion, when they fly away.

With all grubs and all animals that break out from the grub state, generation is due primarily to the heat of the sun or to wind.

Ascarids are more likely to be found, and grow with unusual rapidity, in places where there is a deposit of a mixed and heterogeneous kind, as in kitchens and in ploughed fields, for the contents of such places are disposed to rapid putrefaction. In autumn, also, owing to the drying up of moisture, they grow in unusual numbers.

The tick is generated from couch-grass. The cockchafer comes from a grub that is generated in the dung of the cow or the ass. The cantharus or scarabeus rolls a piece of dung into a ball, lies hidden within it during the winter, and gives birth therein to small grubs, from which grubs come new canthari. Certain winged insects also come from the grubs that are found in pulse, in the same fashion as in the cases described.

Flies grow from grubs in the dung that farmers have gathered up into heaps: for those who are engaged in this work assiduously gather up the compost, and this they technically term "working-up" the manure. The grub is exceedingly minute to begin with; first—even at this stage—it assumes a reddish colour, and then from a quiescent state it takes on the power of motion, as though born to it; it then becomes a small motionless grub; it then moves again, and again relapses into immobility; it then comes out a perfect fly, and moves away under the influence of the sun's heat or of a puff of air. The myops or horse-fly is engendered in timber. The orsodacna or bud-bane is a transformed grub; and this grub is engendered in cabbage-stalks. The cantharis comes from the caterpillars that are found on fig-trees or pear-trees or fir-trees—for on all these grubs are engendered—and also from caterpillars found on the dog-rose; and the cantharis takes eagerly to

ill-scented substances, from the fact of its having been engendered in ill-scented woods. The conops comes from a grub that is engendered in the slime of vinegar.

And, by the way, living animals are found in substances that are usually supposed to be incapable of putrefaction; for instance, worms are found in long-lying snow; and snow of this description gets reddish in colour, and the grub that is engendered in it is red, as might have been expected, and it is also hairy. The grubs found in the snows of Media are large and white; and all such grubs are little disposed to motion. In Cyprus, in places where copper-ore is smelted, with heaps of the ore piled on day after day, an animal is engendered in the fire, somewhat larger than a bluebottle fly, furnished with wings, which can hop or crawl through the fire. And the grubs and these latter animals perish when you keep the one away from the fire and the other from the snow. Now the salamander is a clear case in point, to show us that animals do actually exist that fire cannot destroy; for this creature, so the story goes, not only walks through the fire but puts it out in doing so.

On the river Hypanis in the Cimmerian Bosphorus, about the time of the summer solstice, there are brought down towards the sea by the stream what look like little sacks rather bigger than grapes, out of which at their bursting issues a winged quadruped. The insect lives and flies about until the evening, but as the sun goes down it pines away, and dies at sunset having lived just one day, from which circumstance it is called the ephemeron.

As a rule, insects that come from caterpillars and grubs are held at first by filaments resembling the threads of a spider's web.

Such is the mode of generation of the insects above enumerated.

Lucretius, *On the Nature of Things*, Book V, ll. 783–877. Translated by C. E. Bennett. Walter J. Black, Roslyn, N. Y., 1946.

In the beginning, earth did bring to being
Herbage of every kind and verdure bright
Upon the hills and over every plain,
Till all the flowery meadows were agleam
With vesture green, and mongst the various trees
A mighty contest arose, as each did strive
To rise aloft with every rein let loose
Through the soft airs. And e'en as down and hair
And bristles first are formed upon the limbs

Of fourfoot creatures and the bodies too
Of strong-winged fowls, so then the new-born earth
First reared her shrubs and herbage; then in turn
In order due did bring to birth the tribes
Of mortal creatures, risen in many ways
By means diverse. For ne'er could living beings
Have fallen from heaven, nor beasts that roam the earth
Have issued from the briny pools. With right
It followeth then that earth hath won the name
Of Mother, since from earth have all things sprung.
And even now we see full many a breed
Of living creatures rise from out the earth
Begot by rains and by the genial warmth
The sun doth shed. Hence we may marvel less
If then in larger numbers and endowed
With ampler bulk were creatures brought to birth
And reached their prime, since earth and air were new.
First, then, the winged tribes and every breed
Of flying fowl did leave their eggs, safe hatched
By springlike warmth, as now, in summer's heat,
Locusts will fain put off their polished shells
In quest of life and living. Then it was
That earth did first give birth to mortal beings.
For all the fields did teem with gentle warmth
And moisture. Hence, where there was at hand
Appropriate place, there grew up wombs, attached
By roots to earth; and when, at time fulfilled,
The tiny creatures' growing age, in flight
From moisture and in search of air, had burst
Their prison, so would nature turn toward each
The pores of earth, and from wide-opened veins
Constrain them to exude a sap most like
To milk, as even now, when she hath borne
A child, each woman's breasts are filled forthwith
With sweet new milk, since thitherward are turned
All the rich humors of her nourishment.
Earth gave these little ones their food, the warmth
A garment, and the soft thick-tufted grass
A downy bed. But since the world was young,
No bitter cold it roused, nor heat o'er fierce,
Nor winds of violent might. For evenly
Do all things wax and reach their full-grown strength.

Wherefore once more I do aver that earth
 Hath justly won, and justly doth she keep
 The name of Mother, since 'twas she herself
 Did in her own fixt time create the race
 Of men, and every breed of beast that here
 And yon among the mighty mountain tops
 Doth hold wild revel; and the flying fowl
 Likewise that dwell in air, in all their range
 Of forms and hues diverse. But since at length
 She needs must reach some end of bearing, so
 Did she give o'er, e'en as a woman, worn
 With length of lingering years. For time doth change
 The mold of all the world, and one estate
 Upon another needs must overtake
 All things that be, nor aught doth long abide
 Like to itself, but all things shift their place;
 Yea, nature altereth all, and doth constrain
 Each one to change its form. For one doth wane
 And, worn with age, doth pine, then somewhat else
 Doth rise to take its place and issue forth
 From whilom place of scorn. So then did time
 Bring change to all the nature of the world,
 And one estate upon another seize
 Upon the earth, that so what once it bore
 It can no longer compass, and can bear
 What ne'er it brought to birth in days of old.

And in those days did earth essay to frame
 Full many a monster, born with visage strange
 And limbs awry, the woman-man, midway
 Between the two, yet neither, and apart
 From both; and some there were bereft of feet,
 Or wanting hands in turn, and some were found
 Dumb without mouths, or featureless and blind,
 Or chained through all their frame by limbs that clung
 One to another, so that power they lacked
 To compass aught, or move toward any side,
 Or flee from danger, or to gain what'er
 Their needs required. And other monsters, too,
 And creatures strange would she create, but all
 In vain, since that their nature did forbid
 Increase, nor could they reach the envied bloom
 Of age, nor gather sustenance, nor join

In Venus' arts; for many a requisite
 We see must be fulfilled in living things
 Ere they avail to propagate their kind
 By generation: first, they must have food,
 And then the means whereby from out their frames
 Birth-giving seeds may issue, cast abroad
 From the appropriate members, so that male
 And female may be joined, and each possess
 The means whereby to exchange their mutual joys.

And in those far-off days full many a race
 Of living things must needs have perished, nay,
 Nor aught of offspring could beget and thus
 Preserve its kind; for whatsoe'er we see
 To breathe the vital air of heaven, 'tis craft,
 Or courage, yea, or fleetness that since first
 Their life began hath guarded and preserved
 Their several breeds. And many too there be
 Which by their use commended to our care
 Live on, entrusted to our guardianship.
 First, to the ravening race of lions, that breed
 Of savage beasts, 'tis valor hath vouchsafed
 A sure protection; in the fox 'tis craft,
 The stag, the swiftness of his flying feet;
 But otherwise the lightly slumbering minds
 Of faithful-hearted dogs, and all the breeds
 That spring from seed of burden-bearing beasts
 And fleecy flocks withal, and horned herds;
 All these, good Memmius, are nursed by care
 Of human kind. For eagerly, I ween,
 Have they escaped their savage enemies
 And sought the quietude and plenteous store
 Of sustenance ourselves are pleased to grant
 As wage for service rendered. But those breeds
 Whereunto none of these advantages
 Hath nature granted, so that of themselves
 They cannot live, nor render unto us
 Some useful service, in return wherefor
 We might permit their kind to feed and dwell
 Beneath our safe defense, these, thou mayst know,
 Did fall a prey and spoil to others, each
 Chained by the fateful trammels of its being,
 Till nature brought their kind at length to doom.

THE CREATION OF SCIENCE: INSTRUCTIONS FOR THE POST-SCIENTIFIC AGE

A note to contemporary readers. I have described in this chapter the first generation of science in Greece and Rome. We are now in the second generation of science, which began in the Renaissance. Probably you assume this second generation will continue forever. Aristotle must have felt the same way about his generation of science. Perhaps we should withhold our optimism until modern science has survived at least as long as the interval from Thales to Lucretius. The political and social causes of the decline of Greek science are insignificant compared to the potential consequences of nuclear proliferation and massive retaliation, which technically sane people are now planning in the guise of "nuclear diplomacy." Only a dull wit can fail to imagine the dawn—or dusk—of a new Dark Age as the result of energy shortages, famine, pollution, and so on. The survivors in such catastrophes are not likely to look smilingly upon science to rescue them from a situation which it got them into. Undoubtedly such a turn of events would initiate a Post-Scientific Age. It is not good to dwell upon such a prospect; once we start believing the prophecy that science and civilization are doomed, that prophecy becomes self-fulfilling. Yet I think it would be useful to a Galileo of the Post-Scientific Age to leave some guidance to help him start the third generation of science. As a contemporary reader, you might also find it useful for delaying the coming of the Post-Scientific Age.

Dear Reader of the Post-Scientific Age:

I cannot imagine the circumstances which have brought you and this book together. That you are reading it at all can only mean that many more worthy books of science have been lost or destroyed. Were they lost in some holocaust of our devising? Were they destroyed as evil or heretical? Or did they simply vanish through neglect? Are you reading these words in secret, dreading a knock on the door that will consign you and this book to the flames? Or have you simply stumbled upon it in the dust of some abandoned cellar?

Whatever the circumstances you are apparently interested enough to have read this far. Our theories are probably comical or disturbing to you, but perhaps our way of thinking of nature as being the result of causes and effects seems worthwhile. You may, in fact, be considering a rebirth of scientific thinking. Rather than have you puzzle out an approach yourself, I will reveal to you four of the prerequisites to the establishment of science. I will not guarantee that fulfilling these conditions will automatically create a new age of science, but there is no chance that you will succeed without them.

1. *Create a climate of religious tolerance.* (Well, I never claimed you would have an easy task.) It does happen occasionally that the majority will tolerate a minority with bizarre opinions which conflict with their religious views. In

Milvus I suppose the mortals who ordained themselves the protectors of the gods did not realize the threat implicit in Thales' idea that nature obeys set rules. By the time science began to spread to other shores the Persians had created more serious problems for the defenders of the Greek pantheon than those posed by the Ionian scientists. The execution of Socrates, the suppression of Lucretius, and the activities of my contemporary antievolutionists may serve to warn you how rare such tolerance is. You will be fortunate if you achieve the degree of religious freedom enjoyed in the recent past by those in the United States and a few other Western countries.

There is a strategy that may help you avoid becoming a martyr for science: pretend that science is irrelevant, or better yet, supportive of whatever the prevailing dogmas may be. This may be how Plato avoided becoming a second Socrates. Apparently some of the astronomers in my own time have learned this lesson. In announcing new evidence that the universe began with a "Big Bang" they proclaimed it as support for Genesis and passed over the fact that it is equally consistent with the creation myths of dozens of other religions. If they had found evidence for an eternal, evolving universe they surely would not have proclaimed it as support for Buddhism or Taoism.

In addition to religious intolerance you may also be faced with an intolerance for all "useless" knowledge. Your fellow men will want science to cure their diseases, make their lives easier, and help kill their enemies. They will not want you exercising your mind on such questions as the origins of species, especially if your findings cast doubt on their belief that they were divinely created in the image of God. You may tell them, however, that every material benefit of science began with some scientist puttering around out of curiosity. Let your motto be "Knowledge for the hell of it."

2. *Do not let science become a religion.* An essential difference between science and religion in their purest forms is that science forms communities, and religions form hierarchies. Scientists talk and listen to each other; followers of a religion listen to those above and talk to those below them. The strengths of the scientific community are the same as those in a population which benefits from hybrid vigor and natural selection, except that one deals with ideas and the other with genes. What is wanted in both cases is an absence of inbreeding and an elimination of the unfit. Religious hierarchies, on the other hand, depend upon the stability of the pyramid, with the gods and their interpreters at the top, supported by an expanding base of followers.

There seems to be an inherent tendency for all humans to seek the stability of the pyramid, and scientists are no different. There are some, like Plato, who wish to be at the top of a pyramid. Others are elevated against their will, like Aristotle in the late Middle Ages. Modern science has resisted that tendency well so far, unless one includes Freud, Jung, Pavlov, and some other psychologists. Newton, Darwin, and Einstein are the most revered

figures of modern science, yet any real scientist would be delighted to discover a new error in their work, because he knows that science marches fastest over the corpses of dead theories.

3. *Be prosperous.* History is devoid of poor economies which produced great science. Miletus was a rich seaport; Athens thrived on slavery and the income for its mercenary forces. Following the Renaissance the growth of science was proportional to the growth of the economies of Italy, Britain, France, and Germany. The reasons for the dependence on wealth are not hard to understand, though they vary with the type of science practiced. Greek science was cheap because it was entirely theoretical, but even Aristotle had to eat. He could not have been a scientist without Hermias and Alexander. (It is true that Socrates disdained money, but then he could afford to.) Not only did the upper economic stratum of Greece have to support science, but the lower stratum had to be comfortable enough to tolerate men who, as far as they could tell, did nothing to earn a living. Even if scientists could live entirely on their salary as teachers, there had to be enough wealth and leisure so that students could be spared from supporting themselves and their families.

As science became more experimental in the Renaissance it became more expensive. The first modern scientists supported the building of telescopes, laboratories, and such out of their own pockets, or, more often, out of the pockets of rich patrons. This is a situation you should avoid, since it excludes those who are not servile to the rich. How many Newtons were wasted because they were poor or honest? Following our Second World War the governments of the United States and many other countries began to support scientific teaching and research through tax-funded grants. This arrangement has the advantage of rewarding merit (so much so that many scientists and university administrators act as if getting the money is more important than doing the research), but it has the disadvantage that the support waxes and wanes with the public's generosity, the mood of legislators, and the state of the economy.

4. *Start a war.* Unless humans have evolved greatly since my time this will be the easiest part of your task. In fact, it is difficult for me to prove that science advances most rapidly in time of war because of the scarcity of peaceful times with which to make comparisons. This requirement for science is closely linked to the requirement for prosperity, as the examples of Athens and our Second World War illustrate. It is therefore rather important that you not lose the war or let it debilitate your economy. The best kind of war for the purpose is a cold war, such as existed between the United States and Russia in the 1950s and 1960s. (In case you are not familiar with the term, a cold war is something like you and your neighbor pointing guns at one another's children, and each of you daring the other to shoot first.) During a cold war one can justify virtually any activity by claiming that one's

opponent is doing it better. The formula developed in the United States was to announce that "we are losing the (fill in the blank) Race." For example, an announcement that "we are losing the Chess Race" would result in thousands of Americans patriotically discovering that they had a consuming passion for the game. It helps if you really are losing the race. In 1957, after the Russians launched Sputnik, the first artificial Earth satellite, all sorts of money was provided for scientific research and education to help us win the Space Race. The relation to the cold war was manifest in the fact that much of the money was provided under a National Defense Education Act and by various military agencies. Unfortunately many of the things a progressive society ought to do anyway, it will do only when it perceives itself threatened.

Now that the good old days of the cold war are over, this kind of support for science has slackened. If I were a cynic I might wish that the Russians would accomplish the biological equivalent of Sputnik—perhaps the synthesis of life. You might consider advancing science in your own country by introducing it first to your enemies. Lots of luck.

TABLE 4. MAJOR EVENTS AND PEOPLE OF THE FIRST 13 CENTURIES A.D.

Year A.D.	Science / Philosophy	Arts	Politics & War
1	Pliny (23-79)	Plutarch	Diaspora (70)
100	Ptolemy (100?-178?) Galen (130?-200?)		
200	Plotinus (205-270)		
300			Council of Nicaea (325)
400	Augustine (354-430)		Sack of Rome (410) End of Western Empire (476)
500	Boethius (475?-524)	Cathedral of St. Sophia	
600	Isidore, Bishop of Seville (560?-636?)	Beowulf	Mohammed (570-632)
700	Venerable Bede (673-735)	Gregorian Chant (600-1100)	Battle of Tours (732)

Year A.D.	Science/Philosophy	Arts	Politics & War
800			Charlemagne (768-814)
	School of Salerno (848)		
900		St. Mark's, Venice	
1000	Avicenna (980-1037) University of Cordova	Song of Roland	Battle of Hastings (1066)
	Oxford University		Crusades (1095-1291)
1100	University of Paris Adelard of Bath Averroes (1126-1198)	Omar Khayyam El Cid Notre Dame	Jenghis Khan (1162- 1227)
1200	Albertus Magnus (1193-1280) Thomas Aquinas (1225-1274) Roger Bacon (1214- 1292)	Alhambra	Frederick II (1194- 1250) Magna Carta (1215)
1300			

and in less than five years each American citizen would be the sole member of his very own race!

25. For a relatively simple statement of this problem and an approach to its solution see Prigogine (1973).

2. THE ORIGIN OF SCIENCE: ANCIENT GREECE

1. We should remember that even the staunchest supporters of democracy in Greece owned slaves.

2. This may be the place to point out that there is a difference between agriculture, medicine, and technology on one hand, and science on the other hand. The cultivation of domestic animals and crops, the medicinal use of drugs, and the construction of tools were once based on trial and error, rather than science. Successful procedures were then formalized into religious or other traditions. Remnants of these prescientific practices survive in planting according to the phase of the moon, folk medicine, and other traditions.

Science seems to have been invented independently in China by the followers of Mo Ti (or Mo Tzu), who lived in the fifth century B. C., during the Warring States period. Many Mohist writings were deliberately destroyed because they were critical of Confucius, but surviving fragments include sophisticated theories and a modern appreciation of cause and effect. Implicit in these writings is the idea that cause must precede effect, which does not occur in many other cultures. Even Aristotle allowed that final causes occurred after their effects. See Needham (1969, p. 225) for Mohist science.

3. As we shall see, Empedocles and Aristotle have also been championed as the first evolutionists. There have always been those who delight in proving that the degenerated brains of modern man have been incapable of an original idea since the Greeks. Among those who consider Anaximander an evolutionist are Clagett (1955, p. 53), Sarton (1927, p. 72, 1952, p. 176), and Nordenskiöld (1929, p. 12). Guthrie (1962, pp. 101–104) argues against this conclusion on different grounds from those I use. For sources of the quotations about Anaximander see Guthrie or Burnet (1957, pp. 70–71). See Diogenes Laertius (1950, vol. 1, pp. 130–133) and Gillispie (1970, vol. 1) for the life and thoughts of Anaximander.

4. This is the same Cyrus who freed the Jews from Babylon eight years later. Herodotus (1. 75) says that Thales served as a military engineer in an attack against Cyrus. Thus the dispersal of Ionian science might be considered poetic justice.

5. For the life of Empedocles see Burnet (1957, pp. 197–204), Diogenes Laertius (1950, vol. 2, pp. 366–391), Gillispie (1971, vol. 4), and Lambridis (1976).

6. Among those who regard Empedocles as an evolutionist are Burnet (1957, pp. 242–243), Durant (1966, p. 356), Fothergill (1952, p. 15), and Sarton (1927, p. 87). Burnet interprets the fragments to mean that each of the first animals had both sexes, and that males and females separated later and only then began to reproduce. Burnet must therefore have in mind a definition of evolution which does not require reproduction.

According to Burnet (1957, p. 232), Love and Hate were material rather than

abstract. These same physical forces produced the corresponding emotions in humans. Greeks at this time made no distinction between matter and mental states. Greeks also rejected the idea of action at a distance, such as gravity acting through space, so Love and Hate were not like our forces of attraction and repulsion.

7. The most famous Eleatic paradox is Zeno's proof that Achilles can never catch up to a tortoise because by the time Achilles arrives where the tortoise was, the tortoise will have moved farther. For a solution to the paradox see Grünbaum (1955). For contemporaneous views of the Eleatics and the Sophists see Plato's *Parmenides*, *Protagoras*, and *Sophist*, and Aristotle's *Sophistical Refutations*.

8. *Parts of Animals* I. 1. A. M. Peck, translator.

9. I am assuming that Diogenes Laertius (1950, vol. 1, pp. 148–177) was a more accurate historian than Aristophanes, who portrays Socrates in *The Clouds* as scheming to profit from philosophy and devoting his mind to such concerns as whether a gnat hums out of its mouth or out of its rear end.

10. The quotation is from Plato's *Phaedo*, beginning around section 99. The essence of Socrates is found in this dialogue, especially sections 72–75 and 96–99. The assertion that phenomena of life can be understood from atomic and molecular behavior—reductionism—is still hotly debated by biologists. See for example Ayala and Dobzhansky (1974), Hull (1974, Ch. 5), Koestler (1967), and Koestler and Smythies (1969).

11. For Plato's life see Diogenes Laertius (1950, vol. 1, pp. 276–373), Gillispie (1975, vol. 11), and the supposedly autobiographical *Seventh Letter*.

12. It is doubtful that these views on women were Plato's. He admitted women to the Academy and advocated an equal share for them in government (*Republic* V).

13. See C. U. M. Smith (1976, Ch. 7) for an introduction to the *Timaeus*.

14. For Aristotle's life see Chroust (1973), Diogenes Laertius (1950, vol. 2, pp. 444–483), Gillispie (1970, vol. 1), Grayeff (1974), and Lloyd (1968).

15. For introductions to Aristotle's scientific thought see Grene (1963, 1976), Lloyd (1968), and Randall (1960).

16. This *Scala naturae* became in the Middle Ages the basis for the idea of the Great Chain of Being: that there is a continuous chain linking the Prime Mover, the celestial bodies, man, other animals, plants, and the inanimate. For a discussion of whether Aristotle was an evolutionist, see Torrey and Felin (1937).

17. For the history of science in the last three centuries B. C. see Lloyd (1973), Sarton (1959), and Taton (1963, pp. 262–371).

18. Aristotle rejected the atoms of Democritus not only because of their chaotic motion, but because they would have to have a void between them. Aristotle's logic could not cope with the existence of nothingness. Physicists until early in the present century had the same problem. They found it necessary to postulate an imperceptible ether as the medium in which matter existed and waves were propagated.

19. For the life and thought of Epicurus see Diogenes Laertius (1950, vol. 2, Ch. 10) and Gillispie (1971, vol. 4). Farrington (1966, 1967) has a very different interpretation of Epicurus. Most historians see Epicurus as using scientific explanations of thunder, magnetism, and life primarily to liberate minds from superstitious fears, as one explains the shadows which may frighten children. Farrington argues persuasively that Epicurus was prescribing scientific reasoning as an antidote to the type of state-imposed religion advocated by Plato.

The last sentence of this paragraph is inspired by the passage in *L'Etranger* by Albert Camus, in which Muersault, awaiting his execution, gazes past the bars into the starry night and finds peace in "*la tendre indifférence du monde*."

20. For Lucretius see Gillispie (1973, vol. 8), Sarton (1959, pp. 263–279), and Farrington's (1966) unique interpretation.

In addition to the insights of Lucretius and/or Epicurus already discussed, they also recognized the importance of molecular structure to life (*De Rerum Natura* I, ll. 817–823), the likelihood of life on other planets (II, ll. 1067–1076; Diogenes Laertius, 1950, vol. 2, p. 605), and the constant acceleration of falling bodies regardless of their weights (II, ll. 225–242; Diogenes Laertius, 1950, vol. 2, p. 591). The last discovery is generally credited to Galileo, even though *De Rerum Natura* had been known in Italy since 1418. The reason why Lucretius and Epicurus are underrated as scientists may be such boners as their claim that the sun is no larger than it appears to the eye (V, ll. 564–565; Diogenes Laertius, 1950, vol. 2, p. 619).

3. THE INFANTICIDE OF SCIENCE: ROME AND THE MIDDLE AGES

1. None of these emperor-gods seems particularly divine, but the Stoic Marcus Aurelius (121–180) at least deserves respect for the wisdom and comfort we still find in his *Meditations*. Unfortunately he could not follow his own advice: "No longer talk at all about the kind of man that a good man ought to be, but be such" (*Meditations* X, 16). On Roman science see Stahl (1962).

2. See Gibbon's *Decline and Fall of the Roman Empire*, Chapter 16 for this quotation. This chapter in Gibbon is a history of the early church from Gibbon's usual anti-Christian point of view. Most histories of the early church are at the other extreme, relying too heavily on accounts by early Christians, full of miracles such as flames which refuse to burn martyrs. Also religious historians have often had to pay an intellectual price in order to obtain the *Nihil Obstat* and *Imprimatur* attesting to a work's freedom from doctrinal error.

3. At this point most students of Roman history have an irresistible urge to speculate on the causes of Roman decline. Preachers blame moral decadence and persecution of Christians; Gibbon blamed the Christians; countless cranks and moralizers blame whatever the current fashion in evil happens to be. It would be foolish of me to join their ranks. Still, I would just like to note that the decline began shortly after the last great ancient scientists, Ptolemy and Galen, died.

4. Early church historians have been grateful enough to Constantine to portray him as a model of Christian virtue. Yet within a year after the Council of Nicaea, he killed his wife, son, and nephew for reasons which those same historians saw fit not to record.

5. The year 476 is usually taken as the start of the Middle Ages, although the transition into that period was of course gradual and occurred at different times in different places. The capture of Constantinople in 1453 is regarded by historians as a convenient date to mark the end of the Middle Ages. The Dark Ages are considered to have covered the first five centuries of the Middle Ages.

6. For the life of Augustine see his *Confessions* and Brown (1967).

7. After he became a Christian Augustine did not insist on this interpretation, but