CHAPTER I

The State of Science from 500 A.D. to 1000 A.D.

FROM THE TIME when Greek philosophy and science first penetrated the Roman world during the second and first centuries B.C. to the present, it is an indisputable fact that science reached its lowest ebb in Western Europe between approximately 500 A.D. and 1000 A.D., improving gradually until the influx of Greek and Arabic scientific treatises in the 12th and early 13th centuries introduced a virtually new body of scientific literature. How did such a disastrous state of affairs arise and what perpetuated it for so many centuries?

Because the period in question was preceded by the gradual disintegration and transformation of the Roman Empire and the triumph of Christianity as a state religion, these events almost inevitably serve as the large historical background against which the decline of science must be viewed. As early as the reign of Diocletian (285–305), the political instability of a few centuries had seen the Roman Empire divided into Eastern and Western halves, a division that became irreparable after the death of Theodosius in 395 A.D. During the course of the fifth century, the Western half fell prey to invading Germanic tribes and by 500 A.D. much of it was in their control. Despite subsequent efforts of the Eastern emperor, Justinian, only the trappings of Empire remained—the substance was dead, and Western Europe evolved new forms of social and governmental activity to cope with conditions drastically different from those of a few centuries earlier. With a breakdown of strong central government and the gradual dissolution of the urban life so characteristic of the first few centuries of the Empire, it is hardly surprising that intellectual life in the Western

half suffered. If a reasonable degree of political stability, urban activity, and patronage of some kind, are essential or at least conducive to the pursuit of science, the absence of these enables us to comprehend, in a quite general way, how scientific understanding and achievement could have deteriorated and stagnated over so long a period of West European history.

The triumph of Christianity was, among other things, the culmination of a struggle and competition between mystery religions and cults that began as far back as the Hellenistic period and continued until the emperor Theodosius declared Christianity the only legal religion in 392 A.D. As economic and political oppression grew increasingly burdensome to great masses of people at all levels of society, the mystery religions gained in favor and their doctrines were easily disseminated via the excellent roads linking the far-flung points of the Roman Empire. The cults of Isis, Mithra, Cybele, Sol Invictus (Unconquered Sun), as well as Gnostics, Christians, and others, not only borrowed ideas and rituals from one another but also came to share a few basic beliefs. The world was evil and would eventually pass away. Man, sinful by nature, could achieve immortal bliss if only he turned away from the things of this world and cultivated those of the eternal spiritual realm. Along with varying degrees of asceticism, many of the cults believed in a redeemer god who would die in order to bring eternal life after death to his faithful followers. Even some of the contemporary philosophic schools, such as Neo-Platonism and Neo-Pythagoreanism, sought to guide their adherents toward salvation and union with God and, although they utilized more intellectual means, they were not above employing magic to achieve their ends.

Indeed, acceptance of magic and occult powers was widespread in the Roman Empire during the first few centuries of the Christian era, as evidenced by numerous treatises ascribed to the Egyptian god, Thoth, known to the Greeks as Hermes Trismegistus ("Thrice-great Hermes"). Although it incorporated elements from a variety of current philosophies such as Platonism, Neoplatonism, Stoicism, and others, and drew upon some aspects of contemporary scientific knowledge and theory, Hermetic literature represented a reaction to the traditional rational approach of Greek philosophy and science, for it sought to comprehend and explain the universe by magic, intuition, and mysticism. Because these treatises were attributed to the god Hermes and emphasized Egyptian wisdom, readers uncritically accepted them as works of great antiquity, antedating Plato and perhaps even Moses. They were the re-

positories of a pristine source of ancient wisdom and as such exerted an enormous influence. Even Church Fathers read and admired them. Lactantius (*fl.* 300 A.D.), who read them in the original Greek, was highly respectful toward Hermes, whom he regarded as a Gentile prophet of Christianity. St. Augustine, who read at least one of the treatises in Latin translation and rejected a description of the animation of statues of Egyptian gods by magical means, fully accepted Hermes as one who had exerted a strong moral force in Egypt after the time of Moses but long before the ancient philosophers and sages of Greece. Although a few of the Hermetic treatises were available in Latin translation and exerted an influence during the Middle Ages, their full impact would come in the Renaissance, when they provided a widely accepted guide to the study and appreciation of nature and religion.

Did this intense and widespread search for other-worldly salvation, in which the physical world was either held in contempt or approached by means of magic and occult forces, engage the minds and energies of those who, in an earlier age, would have devoted their talents to science and mathematics? If so, it is not easily detectable, at least not before the victory of Christianity. Indeed, during the first few centuries of the Roman Empire, when Christianity was relatively weak and uninfluential, struggling for survival against its many rivals, some of the greatest scientific works of the ancient world were written (as always in the Greek language), a few of which would exert profound influence on the later course of medieval science and well beyond into the Renaissance.

The first century A.D. saw the significant works of Hero of Alexandria (who wrote on pneumatics, mechanics, optics, and mathematics), Nicomachus (on Pythagorean arithmetic), Theodosius and Menelaus (who wrote on spherical geometry; Menelaus' *Spherics* is especially important for the treatment of spherical triangles and trigonometry). The heights were reached in the second century when Claudius Ptolemy wrote the *Almagest,* the greatest treatise in the history of astronomy until the time of Copernicus in the sixteenth century, as well as technical works in optics, geography, stereographic projection, and even the greatest of all astrological works, the *Tetrabiblos* (known in Latin as the *Quadripartitum,* the four-parted work). In the medical and biological sciences, Galen of Pergamum produced about 150 works embracing both theory and practice. His works formed the foundation of medical theory and study until the sixteenth and seventeenth centuries. Even in the third century significant contributions were made in mathe-

matics by Diophantus in algebra and later by Pappus, who not only wrote commentaries on the great mathematical works of Greek antiquity but, in his *Mathematical Collection,* showed originality and understanding of a high order. These achievements, spread across three to four centuries, were typical of the manner in which Greek science had developed and advanced. Always the product of a small number of men concentrated in a few centers, Greek science was a fragile enterprise able to advance and preserve itself just so long as the intellectual environment was favorable, or at least not overtly antagonistic.

With the triumph of Christianity in the fourth century, that small but essential handful of men, who in previous centuries had somehow managed to comprehend, advance, and perpetuate an inherited body of high-level theoretical science, was no longer produced in the eastern or western parts of the Empire (because Greek was the language of the eastern half and some of the scientific treatises could be read in the original language, a much higher level of comprehension was maintained there; but the spark of originality had flickered out). By 500 A.D., the Christian Church had drawn most of the talented men of the age into its service, in either missionary, organizational, doctrinal, or purely contemplative activity. Honor and glory were no longer found in objective, scientific comprehension of natural phenomena, but rather in furthering the aims of the universal Church.

The intense and bitter polemic against pagan learning and religion, which had marked the long struggle of Christianity, cast a pall of suspicion over Greek philosophy and science. In its moment of triumph, Christianity looked with fear and distrust, if not with downright hostility, upon its fallen foe. But Christians were hardly of a single mind on the matter. The most extreme reaction was represented by Tertullian (*ca.* 160–*ca.* 240) who viewed philosophers as purveyors of damnation and heresy. Any alliance between Athens and Jerusalem was unthinkable. Perhaps more truly representative were those like Justin Martyr (*d. ca.* 163–167) and Clement of Alexandria (*ca.* 150 and *d.* before 215) who looked upon Greek learning and philosophy as the handmaid of theology, to be used for a better understanding of the Christian religion, but not to be studied for its own sake. For just as philosophy had prepared the Greeks to accept Christianity and the perfection of Christ, so might it perform the same good work for others. The Christian dilemma is best illustrated by St. Augustine, whose influence throughout the Middle Ages was enormous. In 386 A.D. he emphasized the importance of the liberal arts which from the time of

classical Greece had included the four sciences of geometry, arithmetic, astronomy, and music. These traditional disciplines were helpful in leading a good life and indispensable for a proper understanding of the universe. Augustine even contemplated the composition of an encyclopedia of the liberal arts which would have included sections on the scientific disciplines mentioned above. Only a small part of this project was ever written, perhaps because in later life his attitude toward pagan and secular learning underwent drastic alteration. A few years before his death, he bitterly regretted his earlier emphasis on the liberal arts and concluded that the theoretical sciences and mechanical arts were in no way useful to a Christian.

Despite obvious concern and trepidation about the potential dangers of pagan learning, of which science and philosophy were integral parts, circumstances forced an uneasy truce and compromise. Virtually the only secular learning available was of pagan origin. Elementary and advanced instruction were permeated with pagan religious, philosophic, mythologic, and literary references. Illustrations in grammar and rhetoric texts were drawn wholesale from pagan sources. Christians who received formal secular instruction inevitably absorbed large quantities of traditional pagan fare. Reluctantly, the Church found it necessary to modify its attitude, if not its uneasiness, about pagan learning and science. Indeed, the account of creation in *Genesis* required Christians to provide a measure of physical explanation about the world, as evidenced by the numerous commentaries on the six days of creation, or hexameral treatises, as they were called, which began to appear in the fourth century. By the fifth and sixth centuries some Christians began to manifest a degree of interest in science, and we must now inquire about the scientific treatises and texts that were available and from which their knowledge and opinions about the world were drawn.

It will be evident in what follows that the societal forces operating to weaken and dilute interest in science in late antiquity were aided and abetted by an independent process whose modest beginnings are clearly discernible as far back as the Hellenistic age (320–30 B.C.) and which would continue unabated through the first five or six centuries of the Christian era. I refer to the handbook and encyclopedic tradition of learning whose objective it was to popularize and disseminate the theories and results—but not the technical content or procedures—of Greek science.

The glorious scientific achievements of classical Greece, climaxed by the monumental contributions of Aristotle, were deepened and ad-

vanced during the Hellenistic age when the works of Euclid, Archimedes, Appollonius of Perga, Hipparchus, and others, in the physical sciences were matched by equally significant contributions in medicine and the biological sciences by the likes of Theophrastus, Herophilus, and Erasistratus. As we have already seen, work at this level continued to the fourth century A.D. But, as in our own day, there must have existed a large educated audience keenly interested in the physical world but with little inclination or ability to tackle the forbidding theoretical works at the highest level. To meet the needs of this group, a host of scientific popularizers predigested and made palatable the technical results of the various sciences which were then incorporated into handbooks and manuals. It comes as no surprise to learn that some of these treatises were filled with conflicting and contradictory reports leaving the reader to reconcile them as best he could.

Greeks who were instrumental in shaping the handbook tradition were the polymath Eratosthenes of Cyrene (*ca.* 275–194 B.C.), who supplied much geographical knowledge to the tradition, Crates of Mallos (*fl.* 160 B.C.), and especially Posidonius (*ca.* 135–51 B.C.), whose numerous works have not survived, but whose opinions on meteorology, geography, astronomy, and other sciences were absorbed into later handbooks to become permanent fixtures in the tradition. Continuing in the manner of Posidonius were other Greek authors such as Geminus (*ca.* 70 B.C.), Cleomedes (first or second century A.D.), who wrote an astronomical and cosmological work *On the Cyclic Motions of the Celestial Bodies,* and Theon of Smyrna (first half of the second century A.D.), who wrote a *Manual of Mathematical Knowledge Useful for an Understanding of Plato* in which the whole universe is discussed, as in Plato's *Timaeus,* drawing information from Hellenistic astronomy, cosmology, and Pythagorean arithmetic and mathematics. Commentaries on Plato's *Timaeus* constituted a significant part of the handbook tradition from the Hellenistic period to the early Middle Ages. Since the *Timaeus* was a scientific treatise concerned not only with the cosmos but also with the physical structure and functions of man, it was an admirable vehicle for a handbook discussion since physical and biological material could be appropriately included.

When, as a consequence of their conquest of Greece, Roman gentlemen were brought into contact with Greek culture during the course of the second and first centuries B.C., the Greek handbook tradition was firmly established and its treatises were admirably adapted to cater to Roman cultural interests. For although the Romans were impressed and

awed by Greek intellectual accomplishments, they had no interest in theoretical and abstract science. Hence when fashion dictated that cultured Romans acquire a nodding acquaintance with the results of Greek science, the handbook method was readily available. Undoubtedly some Romans, who learned Greek, could consult the Greek handbooks directly, but the great majority probably absorbed their knowledge through Latin translations. Soon, Romans themselves began compiling their own handbooks on science, and, not surprisingly, these were inferior to their Greek counterparts.

Although the Latin encyclopedic tradition actually began in the first century B.C. with Marcus Terrentius Varro (116–27 B.C.), its two most significant early representatives were Seneca (*d.* 68 A.D.) and Pliny the Elder (23/24–79 A.D.). In his *Natural Questions,* Seneca concerned himself largely with geography and meteorological phenomena (for example, rainbows, halos, meteors, thunder, and lightning) after the manner of Aristotle's *Meteorology.* He drew heavily upon Aristotle, Posidonius, perhaps his major authority, Theophrastus, and other Greek sources. Since Seneca frequently drew morals from natural phenomena, his book was popular with Christians. Of importance was the fact that it passed into the Middle Ages an estimate of the size of the earth that was small enough to encourage men like Columbus and others to think that the oceans were sufficiently narrow to be readily navigable. In it was also struck an optimistic note on the progress of science and knowledge when Seneca predicted that continuous research would reveal nature's secrets.

Pliny's *Natural History* in 37 books was a remarkable scissors and paste collection of enormous scope and detail. By his own estimate, he examined about 2000 volumes drawn from 100 authors. In Book I, Pliny presents a detailed outline of the topics and a full list of the authorities used for each of the 36 volumes that follow. Thus did he honor, rather than plagiarize, his predecessors. A total of 473 authors are listed of whom presumably the 100 mentioned above were primary and some of the others known either through intermediaries or perhaps used cursorily for isolated bits of factual information. Book II is devoted to cosmography, Books III to VI to regional geography, Book VII to human generation, life, and death, Books VIII to XXXII are concerned with zoology and botany, including fabulous animals and the curative powers associated with animals and plants, and Books XXXIII to XXXVII consider mineralogy.

As an indefatigable compiler, Pliny emphasized the curious and the

odd in natural phenomena. Although confusions, inconsistencies, and misunderstandings abound throughout, the weakest sections are those which involve attempted explanations of Greek theoretical science, which Pliny scarcely comprehended.

If Pliny's work was confused and frequently inconsistent, it was at least the product of great diligence coupled with an honest respect for the sources which provided the grist for his insatiable mill. With a few notable exceptions, his successors shared little of his finer instincts. In their compilations plagiarism and incomprehension became characteristic features. Thus Solinus, who lived in the third or fourth century A.D., compiled an encyclopedic work titled *Collection of Remarkable Facts,* the most remarkable fact being that it was largely plagiarized from Pliny. Solinus, in turn, was so thoroughly plagiarized that modern scholars are frequently unable to determine whether Pliny or Solinus was the source of this or that later opinion. Encyclopedic authors looked upon available handbooks as store houses of information in the public domain which could be plundered, embellished, and rearranged to suit their purposes. The final products were then paraded as learned treatises drawn directly from the original sources. The scientific works and opinions of such great figures as Plato, Aristotle, Archimedes, Euclid, Theophrastus, and others, were cited repeatedly in the handbooks as if the compiler had direct knowledge of them. In almost all instances, however, it is painfully evident that he had no direct acquaintance with the great scientific authors of the past and was but repeating—and very likely distorting—what a slightly earlier compiler had already repeated and distorted from his predecessors.

Between the fourth and eighth centuries, encyclopedic authors produced a series of Latin works that were to have significant influence throughout the Middle Ages, especially prior to 1200. Among this group, the most important were Chalcidius, Macrobius, Martianus Capella, Boethius, Cassiodorus, Isidore of Seville, and Venerable Bede. Chalcidius (*fl. ca.* fourth century A.D.) translated most of Plato's *Timaeus* into Latin and added a commentary whose astronomical portions he plagiarized from Theon of Smyrna's *Manual.* Macrobius (*fl.* 400 A.D.), a Neoplatonist, incorporated encyclopedic learning in a commentary on Cicero's *Dream of Scipio,* which is actually Book VI of Cicero's *Republic.* Martianus Capella (*fl.* 410–439) wrote the popular *Marriage of Philology and Mercury,* an ornate, florid account of the seven liberal arts and a pale reflection of classical learning and wisdom. Boethius (*ca.* 480–524) was one of the best of the Latin encyclopedists

and possessed a good knowledge of Greek. He wrote on the *quadrivium* (a term he may have introduced for the four mathematical sciences of the seven liberal arts) but only the treatises on music and Pythagorean arithmetic survive, the latter in the form of a free translation of Nicomachus' *Introduction to Arithmetic*. To these he added his translations of some of Aristotle's logical treatises, perhaps Euclid's *Elements*, and unspecified works of Archimedes which have not survived. His commentaries on certain of the philosophical treatises that he translated and his most famous work, *On the Consolation of Philosophy*, written in prison while awaiting execution, were very influential. Cassiodorus (*ca.* 488–575) included sections on the seven liberal arts in his *Introduction to Divine and Human Readings* and was reasonably scrupulous about citing his authorities. Isidore of Seville (*ca.* 560–636), in addition to a treatise *On the Nature of Things*, compiled a vast encyclopedia called *The Etymologies*. The first three of its twenty books were concerned with the seven liberal arts; others were devoted to medicine and zoology. Finally, Venerable Bede (*ca.* 673–735) was one of the most intelligent of the Latin encyclopedists. In addition to a conventional encyclopedia, *On the Nature of Things*, he wrote two treatises, *On the Division of Time* and *On the Reckoning of Time*, which were concerned with calendar reckoning and considered such topics as chronology, astronomy, calendrical computations, Easter tables and the tides. Although he borrowed heavily from his predecessors, especially Isidore, Bede was capable of adding intelligently to his meager inheritance. For example, he formulated the concept of "establishment of the port," and recorded that the tides recur at approximately the same time at a particular place along the coast, although the times of occurrence vary from place to place.

Taken together, these books contained virtually the sum total of general scientific fact and comprehension through the early Middle Ages. They confronted subsequent authors with an unsystematic, chaotic, and conflicting mass of frequently irreconcilable and incomprehensible information above which few could rise until new scientific learning became available from Arabic and Greek sources. As an illustration of the confusions which abounded in the scientific literature available in the early Middle Ages let us consider an astronomical problem involving the motions of the sun, Mercury, and Venus and the fixed order of the planets. By the fourth century B.C., it had already been observed that Mercury and Venus were always seen as morning or evening stars never farther from the sun than approximately 29 and 47 degrees respectively,

whereas Mars, Jupiter, and Saturn were observable at any angular distance from the sun. To interpret these astronomical facts, Heraclides of Pontus (*ca.* 388–*ca.* 310 B.C.) had argued that while Mars, Jupiter, and Saturn revolved directly around the earth as their physical center, Mercury and Venus, the inferior planets, were exceptions revolving directly around the sun, which in turn revolved around the earth. (See Figs. 1 and 2.)

When in the seventeenth century Tycho Brahe extended this theory and assumed that *all the planets* circled the sun, which, in turn, revolved annually around the earth, it was proposed as a serious alternative to the Copernican heliocentric system. Heraclides' proposal was obviously of potential importance in the history of astronomy, for it represented a major disagreement with Aristotle's cosmology in which *all* planetary motions were assumed to have the earth as their physical center. Indeed it also entailed a denial of a single fixed planetary order with respect to the earth, since at times the order would be sun, Mercury, and Venus (Fig. 1) and at other times Venus, Mercury, and sun (Fig. 2).

Knowledge of the Heraclidean system has been reconstructed from four Latin authors, three of whom are the encyclopedists, Chalcidius (he alone mentions Heraclides by name), Capella, and probably Macrobius. Despite their apparent acceptance of it, all discuss the fixed order of the planets, which presupposes a commitment to an unalterable order for the sun, Mercury, and Venus. Thus Macrobius prefers Plato's arrangement (earth, moon, sun, Venus, Mercury, etc.) to Cicero's (earth, moon, Mercury, Venus, sun, etc.), remaining blissfully unaware of the incompatibility of either order with the movements of Mercury and Venus above and below the sun. Similarly, Martianus Capella, in the very paragraph in which he wholeheartedly adopted the Heraclidean system, for which he was praised by Copernicus, presents the two tradi-

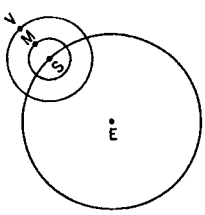

Figure 1

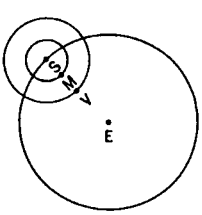

Figure 2