EIGHT
Science in Islam

LEARNING AND SCIENCE IN BYZANTIUM

While the classical tradition was slowly declining in the Latin West, and natural philosophy was being transformed into the handmaiden of theology and religion, what was happening in the Greek-speaking East? Although the East experienced many of the same misfortunes as the West—invasion, economic decline, and social upheaval—the consequences were less severe. A higher level of political stability was maintained, as the eastern half of the old Roman Empire gradually separated itself from the West, giving rise to what we now call Byzantium or the Byzantine Empire, with its capital in Constantinople (present-day Istanbul). That the city of Constantinople did not fall to invaders before 1203, while Rome was sacked as early as the fifth century, tells us something about the relative levels of stability. Greater social and political stability meant greater continuity in the schools; the tradition of classical studies thus waned more slowly in Byzantium and never entirely disappeared; and, of course, the East never found itself separated from the original sources of Greek scholarship by a linguistic barrier.[1]

But it does not follow that natural philosophy and mathematical science flourished. The study of nature was as impractical in the East as it was in the West; the fathers of the Greek church had the same ambivalence toward it as did their Western counterparts, and shared the same determination to subordinate it to theology and the religious life. Scholarly interests in the East were generally theological or literary. Authors felt obliged to limit themselves to the structure and vocabulary of the classical period; this led to imitative tendencies that (it is often claimed) stifled creativity. Insofar as philosophical labors were undertaken, they tended toward commentary on the classical authors; such commentary inevitably included a small amount of natural philosophy, mathematical science, and medicine.

These are sweeping generalizations, of course, and we must be careful not to leave the impression that scholarly achievement was absent or limited. The Platonic tradition (more accurately called the "Neoplatonic tradition," since it departed from Plato on many important matters) was represented by a series of distinguished scholars. Although there was no longer a living peripatetic tradition, there were attempts to assimilate Aristotelian to Platonic philosophy; and certain philosophers of the Byzantine period wrote important commentaries on Aristotle, in which they explained, embellished, or criticized his philosophy of nature, addressing the Aristotelian texts with a level of sophistication unmatched by any Latin-speaking contemporary.

Themistius (d. ca. 385), who taught philosophy in Constantinople and served as tutor to the imperial offspring, wrote influential paraphrases and summaries of a variety of Aristotelian works, including the *Physics, On the Heavens,* and *On the Soul.* Simplicius (d. after 533), an Athenian Neoplatonist determined to reconcile Platonism and Aristotelianism, wrote intelligent commentaries on these same three works. And John Philoponus (d. ca. 570), a Christian Neoplatonist who taught in Alexandria, wrote commentaries on Aristotle's *Physics, Meteorology, On Generation and Corruption,* and *On the Soul.* In these commentaries he attempted, in conscious opposition to Simplicius, to demonstrate the profound errors propagated by Aristotle, including the celestial-terrestrial dichotomy and the notion of an eternal universe. He also offered a systematic and original refutation of Aristotle's theory of motion, denying Aristotle's explanation of projectile motion and the claim that heavy bodies fall through a medium with speeds proportional to their weights. Through the eventual translation of their works into Arabic and Latin, all three men—Themistius, Simplicius, and Philoponus—helped to determine the subsequent course of Aristotelian natural philosophy.[2]

The argument, then, is that Byzantine intellectual life was in decline, like that in the West, but less precipitously; and we can find examples of sophisticated scholarship within the Byzantine Empire that cannot be matched anywhere in the Latin-speaking world. But this was not the only difference. The East also participated in a critically important process of cultural diffusion by which Greek learning was transmitted to far-flung regions of Asia and North Africa, where it would subsequently be assimilated by non-Greeks. This process of diffusion and assimilation is the real subject of the present chapter.

THE EASTWARD DIFFUSION OF GREEK SCIENCE

Although Greek influence had long extended beyond the Greek homeland, cultural diffusion as a conscious policy began with the military campaigns of Alexander the Great.[3] When Alexander conquered Asia and North Africa (334–323 B.C.), he not only acquired territory but also established beachheads of Greek civilization. His campaigns took him as far south as Egypt, as far east as Bactria (in Central Asia near the present-day Soviet-Afghan border) and beyond the Indus River into the northwestern corner of India (see map 2). Behind him he left garrisons and a batch of cities named Alexandria (at least eleven); successful efforts at colonization enlarged the Greek presence, and in the long run these Greek cities became centers of Greek culture, from which Hellenism could emanate into the surrounding regions. The most notable centers of Greek culture thus established were Alexandria in Egypt and the Kingdom of Bactria in Central Asia.

But conquest and colonization were not the only mechanisms of diffusion. Religion also played a decisive role in the spread of Greek learning. Many of the details are obscure, but for our purposes a sketch may be sufficient. In the millennium after Alexander's conquests, his Asian territories (especially, present-day Syria, Iraq, and Iran) proved to be fertile ground for a variety of major religious movements. At one time or another Zoroastrianism, Christianity, and Manicheism contended with each other for converts; all three were based on sacred books and thus, of necessity, cultivated at least a measure of learning. Christianity and Manicheism, in particular, had acquired Greek philosophical underpinnings and thus contributed to the Hellenization of the region. Let us concentrate our attention for a moment on the Christian contribution.

There was a strong Christian presence in Syria from the beginning; and in the first few centuries of the Christian era missionary activity led to the establishment of Christian churches through a wide region of western Asia. In the fifth and sixth centuries, reinforcements arrived in the form of dissident Christian sects seeking refuge from persecution. The Christianization of the Byzantine Empire in the fourth century had led to a series of bitter theological disputes and rifts within the Byzantine church. The most critical of the disputes for our purposes concerned Christ's nature—specifically, the relationship between Christ's humanity and divinity. The extreme positions—that of the Nestorians, who emphasized Christ's humanity over his divinity, and that of the Monophysites, who leaned in the other direction—were condemned in church councils held in 431 and 451.[4] During the ensuing conflict, Nestorian leaders established themselves in the school at Edessa in Syria (then the eastern limit of the Byzantine Empire). Struggle with the Monophysites (who were strong in Syria) and the eventual closing of the school by order of the emperor in 489 caused the Nestorians to seek refuge in the city of Nisibis, to the east, just over the Persian border. There, with the encouragement of the local bishop, they created a center of Nestorian higher education. Biblical studies and theology were the focus of attention, of course, but Aristotelian logic (one of the necessities of serious theology) was also taught, along with other aspects of Greek philosophy. Nisibis may also have developed a program of medical instruction.

From this foothold in Persia, the Nestorians managed, in the next century, not only to shape Persian Christianity, but also to exercise a broad influence on Persian intellectual life. By steps that we only dimly understand, Nestorians managed to insinuate themselves into positions of power and influence and to impart a taste for Greek culture in the Persian ruling class. We see the results in the invitation issued by the Persian king Khusraw I about 531, to the philosophers from the Academy in Athens (expelled by a decree of the Byzantine Emperor Justinian), to settle in Persia. This same Khusraw is reputed to have been knowledgeable in Platonic and Aristotelian philosophy and to have had Greek philosophical works translated for his use; Nestorian connections are revealed in his treatment by a Nestorian physician. Khusraw II (590–628) had two Christian wives—one of them, at least, a Nestorian before her conversion to Monophysitism—and an influential physician-advisor who also vacillated between the Nestorian and Monophysite sects.[5]

An influential mythology has developed around Nestorian activity in the city of Jundishapur in southwestern Persia. According to the often-repeated legend, the Nestorians turned Jundishapur into a major intellectual center by the sixth century, establishing what some have chosen to call a university, where instruction in all of the Greek disciplines could be obtained. There is alleged to have been a medical school, with a curriculum based on Alexandrian textbooks, and a hospital modeled on those that had developed within the Byzantine Empire, which kept the realm supplied with physicians trained in Greek medicine. Moreover, Jundishapur is held to have played a critical role in the translation of Greek scholarship into Near Eastern languages and, indeed, to have been the single most important channel by which Greek science passed to the Arabs.[6]

Recent research has revealed a considerably less dramatic reality. There

is no persuasive evidence for the existence of a medical school or a hospital at Jundishapur, although there seems to have been a theological school and perhaps an attached infirmary. No doubt Jundishapur was the scene of serious intellectual endeavor and a certain amount of medical practice—it furnished several physicians for the Islamic court at Baghdad in the eighth century—but it is doubtful that it ever became a major center of medical education or of translating activity. If the story of Jundishapur is unreliable in its details, the lesson it was meant to teach is nonetheless a valid one. Nestorian influence, though not focused on Jundishapur, did play a vital role in the transmission of Greek learning to Persia and ultimately to the Arabs. There is no question that Nestorians were foremost among the early translators; and as late as the ninth century, long after Persia had fallen to Islamic armies, the practice of medicine in Baghdad seems to have been monopolized by Christian (probably Nestorian) physicians.[7]

But there is a linguistic shift here, which we must also take into account. Although the content of the education available in Nisibis, Jundishapur, and other Nestorian centers was predominantly Greek, the language of instruction was not. Teaching was in Syriac, a Semitic tongue (a dialect of Aramaic) widespread in the Near East; this, along with Greek, was the language of culture in Persia, and it was adopted by the Nestorians as their literary and liturgical language. The teaching program, then, required the translation of Greek texts into Syriac. Such translations were made at Nisibis and other locations, beginning as early as 450. Again we are short on detail, but logical works by Aristotle and Porphyry appear to have been among the earliest translated. Medical literature, works on mathematics and astronomy, and various philosophical treatises were eventually rendered as well.

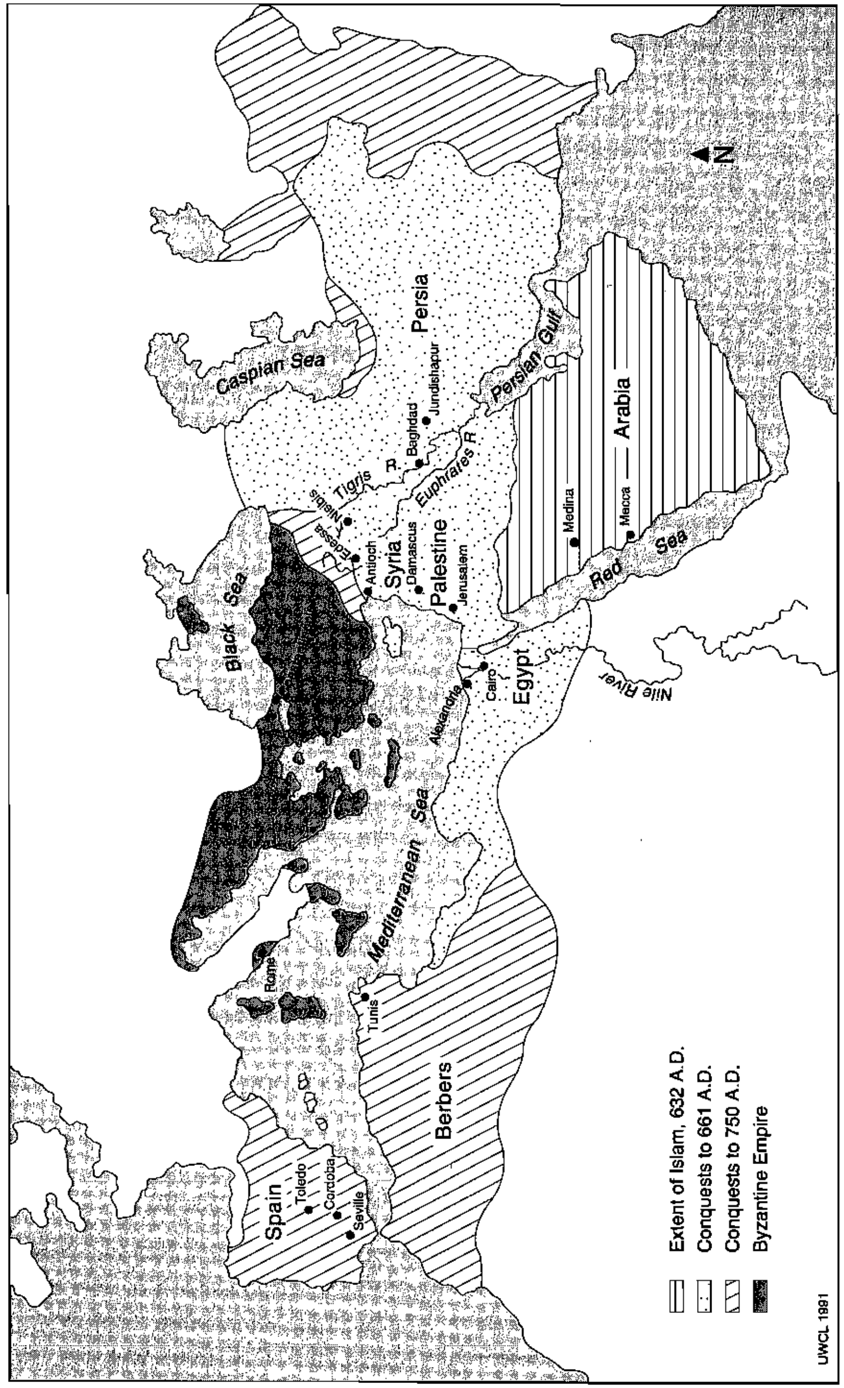
Several points merit special emphasis. First, let us be clear that this is a story about the *transmission* of learning. Our subject (in the early sections of this chapter) is not original contributions to natural philosophy, but the preservation and eastward diffusion of the Greek heritage into Asia, where it would subsequently be absorbed into Islamic culture. Second, this process of cultural diffusion was quite slow, but also of very long duration—occupying a period of nearly a thousand years, from the Asian conquests of Alexander the Great (about 325 B.C.) to the founding of Islam in the seventh century A.D. Third, the story must not be oversimplified to the point where the diffusion of Greek learning is viewed as hanging on the slender thread of Nestorian activity in the city of Jundishapur or any other specific location. Rather, we must see this as a wide movement of cultural diffusion, whereby the aristocracies of western Asia assimilated broadly and deeply, and by a variety of mechanisms, the fruits of Greek culture. We must now consider the further transmission of those fruits to Islam.

THE BIRTH, EXPANSION, AND HELLENIZATION OF ISLAM

The Arabian peninsula, wedged between Persia to the north and east and Egypt to the west, had been untouched by Alexander's military campaigns and not much affected by Byzantine territorial ambitions. Jewish and Christian communities had flourished for a time in the south, but by the seventh century their influence had diminished to a modest level. Except on the southern and northern edges, the population was largely nomadic, although cities had been established around pilgrimage sites and along the major trading routes. It was in one of these cities, Mecca, that Muḥammad was born late in the sixth century and from which he preached the new religion of Islam. Muḥammad had a series of revelations in which the Koran (or Qurʾān, the holy book of Islam) was dictated to him by the angel Gabriel. The central theme of these revelations was the existence of a single omnipotent, omniscient god, Allah, creator of the universe, to whom the faithful (called "Muslims" or "Moslems") must submit. This book came to define all aspects of Islamic faith and practice; it was the source of Islamic theology, morality, law, and cosmology, and thus the centerpiece of Islamic education; it served to codify Arabic as a written language, and it remains the principal model for Arabic literary style.[8]

Muḥammad both practiced and taught the necessity of holy war and compulsory conversion. Before his death in 632, his band of followers had overrun the Arabian peninsula and conducted successful raids to the north; after his death Muslim forces emerged from their homeland and rapidly put both Byzantine and Persian armies to flight, thus gaining control of major portions of the Near East. In twenty-five years of stunning military success, Islam subjugated almost the whole of Alexander's Asian and North African possessions, including Syria, Palestine, Persia, and Egypt. Within a century, the remainder of North Africa and almost the whole of Spain fell to Muslim arms.

Muḥammad left no male heir or designated successor; consequently leadership of the developing Islamic Empire became a matter of bloody dispute. The first caliphs ("successors" of Muḥammad) were chosen from Muḥammad's early followers. In 644 ʿUthman of the Umayyad family became caliph, and in 661 his cousin Muʿāwiyah, who had been governor of Syria. In the interests of security, Muʿāwiyah and his successors ruled from



Map 4. Islamic Expansion

Damascus in Syria, where Umayyad strength was concentrated. Here the Umayyad dynasty, which held power for about a century, came into contact with educated Syrians and Persians, whom it used as secretaries and bureaucrats; and thus on a small scale began the Hellenization of Islam.

The process of Hellenization accelerated after 749. In that year a new dynasty, the ʿAbbasids (descended from Muḥammad's uncle, al-ʿAbbās), came to power. The ʿAbbasid caliphs had no intention of remaining in Damascus: like the Umayyads a century earlier, they wanted their capital situated in friendly territory. In 762, al-Manṣūr (754–75) built a new capital, the city of Baghdad, on the Tigris River. Al-Manṣūr's court in Baghdad was not famous for piety but cultivated a religious climate that was relatively intellectual, secularized, and tolerant. More importantly, the Islamic Empire was being transformed from a warrior aristocracy into a centralized state, which called for a much more substantial administrative bureaucracy than anything Muḥammad, his immediate successors, or the early Umayyads could have imagined. The staffing of this bureaucracy could hardly be accomplished from among the warriors who made up the conquering armies, and the caliphs had no reasonable alternative but to make use of educated Persians (generally recent converts to Islam, though the use of Christians was not unknown).

The Persian influence is especially apparent in the powerful royal advisors from the Barmak family—formerly from the province of Bactria and recent converts to Islam. Khālid ibn Barmak served al-Manṣūr; and his son Yaḥya became vizier (chief advisor and tutor of the caliph's heirs) under al-Manṣūr's grandson, Hārūn ar-Rashīd (786–809). The Christian influence is most clearly evident in the practice of medicine at court. In 765, al-Manṣūr was treated by a Nestorian physician from Jundishapur, Jūrjīs ibn Bakhtīshuʿ. Jūrjīs was apparently successful, for he remained in Bagdad as the caliph's personal physician, becoming a powerful court figure; his son succeeded him, and for several generations the Bakhtīshuʿ family held the post of court physician. Finally, it is important to note that there were also influences emanating from India in the east; some of these were the long-term result of the earlier Hellenization of India.

TRANSLATION OF GREEK SCIENCE INTO ARABIC

The translation of Greek and Syriac works into Arabic began under al-Manṣūr, but became serious business under Hārūn ar-Rashīd, who sent agents to Byzantium in search of manuscripts. Al-Ma'mūn (813–833), Hārūn's son, founded a research institute, the House of Wisdom, in

Baghdad; and here translation reached its peak. At the head of the House of Wisdom was Ḥunayn ibn Isḥāq (808–73)—a Nestorian Christian and an Arab, descended from an Arab tribe that had converted to Christianity long before the religion of Islam existed. Ḥunayn, who studied medicine with the distinguished physician Ibn Māsawaih, was bilingual from childhood in Arabic and Syriac; as a young man he went to the "land of the Greeks" (perhaps Alexandria), where he acquired a thorough mastery of Greek. Returning to Baghdad, he attracted the notice of a member of the Bakhtīshuʿ family and a set of wealthy brothers (the "sons of Mūsa"), and through these patrons he was introduced to al-Ma'mūn. At some point Ḥunayn accompanied an expedition to Byzantium, in search of manuscripts. He served as translator under several caliphs and finished his career as chief royal physician, replacing one of the Bakhtīshuʿ.[9]

Ḥunayn's translating activity is of such critical importance as to deserve our careful attention. Ḥunayn was assisted by his son Isḥāq ibn Ḥunayn, his nephew Ḥubaysh, and others. Many of their translations were collaborative efforts. For example, Ḥunayn might translate a work from Greek to Syriac, whereafter his nephew would render the Syriac text into Arabic. Ḥunayn's son Isḥāq translated from both Greek and Syriac into Arabic, as well as revising the translations of his colleagues. And Ḥunayn, besides producing his own translations from Greek to Syriac or Arabic, seems to have insisted on checking the translations of his charges. Ḥunayn and his co-workers were extremely sophisticated in their methods. They understood the need to compare manuscripts whenever possible, in order to weed out errors. And instead of following the common translating practice of mechanical word-for-word substitution (which suffers from the severe disadvantage that not every Greek word has a counterpart in Arabic or Syriac, while failing also to take into account syntactical differences between the languages), Ḥunayn grasped the meaning of a sentence in the original Greek and rendered it by a sentence of equivalent meaning in Arabic or Syriac.

The bulk of Ḥunayn's translations were medical, with special emphasis on Galen and Hippocrates. He rendered about ninety of Galen's works from Greek to Syriac and about forty from Greek to Arabic. He translated some fifteen Hippocratic works. Ḥunayn also translated (or corrected) three of Plato's dialogues, including the *Timaeus;* translated various Aristotelian works (in most cases from Greek to Syriac), including the *Metaphysics, On the Soul, On Generation and Corruption,* and part of the *Physics;* rendered a variety of other works on logic, mathematics, and astrology; and produced a Syriac version of the Old Testament. Ḥunayn's son Isḥāq translated more Aristotle, as well as Euclid's *Elements* and Ptolemy's *Almagest.*

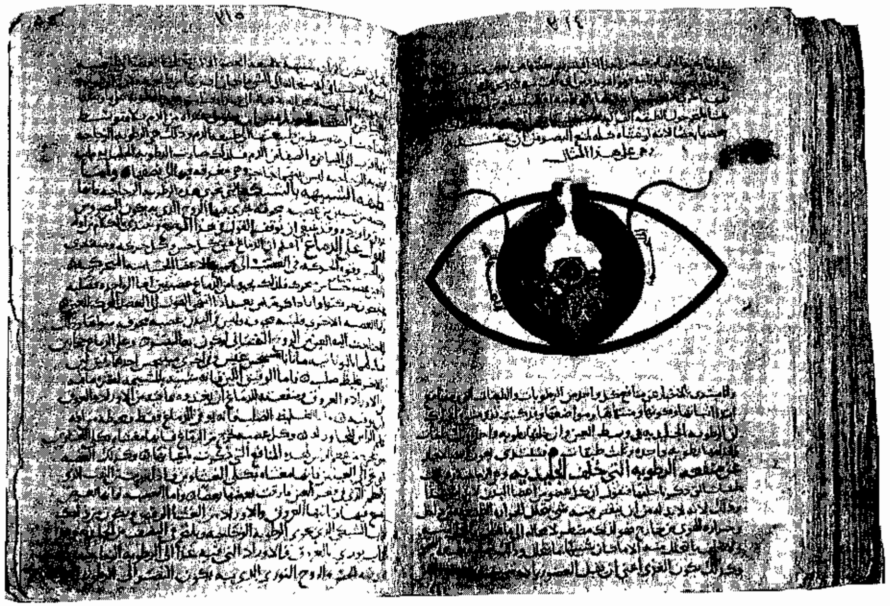


Fig. 8.1. Ḥunayn ibn Isḥāq on the anatomy of the eye, from a thirteenth-century copy of Ḥunayn's *Book of the Ten Treatises of the Eye,* Cairo, National Library.

Their co-workers in Baghdad and their contemporaries elsewhere added to these translations; for example, Thābit ibn Qurra (836–901), a trilingual pagan (that is, neither a Christian nor a Muslim) who spent most of his career in Baghdad, translated mathematical and astronomical treatises, including works of Archimedes. Translation activity continued at a high level for more than a century after Ḥunayn and Thābit. By the year 1000 A.D., almost the entire corpus of Greek medicine, natural philosophy, and mathematical science had been rendered into usable Arabic versions.

THE ISLAMIC RESPONSE TO GREEK SCIENCE

But the question arises: usable for what? What did members of the Muslim ruling caste see in Greek science that made them willing to pay for translations and support scholarship in Greek scientific disciplines? How were the translated works received by these patrons and by literate Muslims more generally? What functions did Greek science serve in the Islamic

world, and how well did it blend with other aspects of Islamic culture? In particular, was there a religious price that had to be paid for the acceptance of Greek science?

We know in general what was translated, and in many cases we know whom to thank. But rarely do we have any exact knowledge of the motivations that lay behind a particular translation. One factor that must have been almost universal is that the patrons of translation were literate, or aspired to literacy, or at least wished to be associated with literacy (if only for the prestige it bestowed); they were people who wished to participate, in one way or another, in the most advanced intellectual culture available. But an explanation in terms of the cultural level of the patrons and recipients seems insufficient. These cultured Muslims were willing to invest in Greek science because they believed (rightly or wrongly) that it had value—that it contributed to the achievement of some worthwhile end. The pursuit of knowledge for its own sake was never endorsed by Islamic religious ideology, nor by any other thread in the cultural fabric. As in medieval Christendom, science was justified by virtue of its utility.[10]

Medicine is a science of apparent utility, and it may well be medicine that first attracted Muslim patronage; certainly medical translations were among the earliest. Medicine, in turn, called for philosophical equipment—or so the reader of Galen's works would gather. Indeed, Galen himself had written on logic and used natural philosophy in his medical writings; and it must have been clear to the translators and their patrons that a full grasp of Galen's medical philosophy demanded a broad knowledge of Greek thought, including Platonic and Aristotelian philosophy.[11] The utility of astronomy, astrology, mathematics, alchemy, and a certain amount of natural history must also have been evident. And finally, in Islam there were successful attempts to create a scholastic theology, imbued with Greek logic and metaphysics. It would appear, then, that the translation of almost any Greek medical, mathematical, or philosophical work could (with only a little stretching) be justified on utilitarian grounds: some were of critical importance; the rest must have seemed at least vaguely useful.

There was no necessary connection between the translation of a book into Arabic and its wide dissemination in Islam or the assimilation of its contents into Islamic culture. After all, translation requires only a translator and perhaps a patron, while dissemination and assimilation are broad cultural phenomena. Once the linguistic barrier had been surmounted through translation, formidable obstacles remained. One of them was the

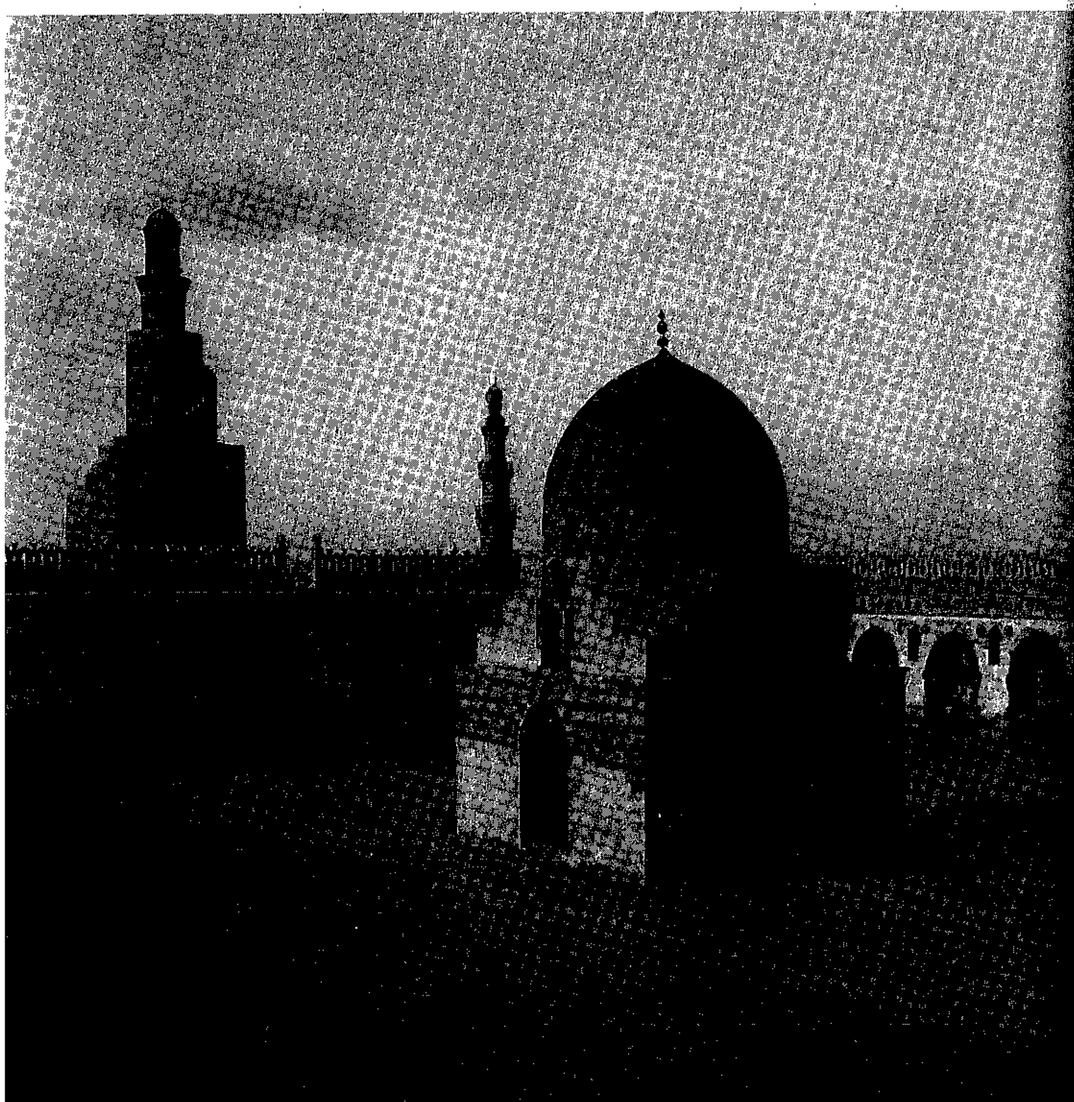


Fig. 8.2. Ibn Tūlūn Mosque (9th century), Cairo. Foto Marburg/Art Resource N.Y.

lingering question of utility, which could not be answered for a culture, as it might for a patron, with a wave of the hand. To the strict Muslim, knowledge was always a means rather than an end, subordinated to the achievement of personal salvation, the acquisition of wisdom (defined in religious terms), the government of the Islamic commonwealth, or some other manifestly practical purpose.

Another obstacle that Greek science had to overcome was its foreign origin and its rational character. Muslims themselves divided learning into two categories: traditional, on the one hand; foreign or rational, on the other. The traditional disciplines were those based on the Koran: grammar, poetry, history, theology, and law. These rested on divine authority and were often taught orally (reflecting the oral nature of Muḥammad's revelations and his own teaching); the obligation of the practitioner of such disciplines was completeness and fidelity of transmission. By contrast, the foreign disciplines obtained from the Greeks were of human rather than divine origin; they were to be apprehended by reason, rather than accepted on the basis of authority or tradition; their transmission was primarily by means of the written word, and they were subject to critical commentary and correction. Any attempt to apply the methodology of the foreign sciences to the traditional disciplines would run obvious risks; and it was inevitable, therefore, that the foreign sciences should be seen as a threat by people of conservative bent.

What, then, was the fate of the foreign sciences in Islam? No simple answer, applicable to all times and places, is possible. Indeed, the historical situation was so complex that historians who specialize on Islam cannot agree on how to characterize it. Two quite different interpretations are currently in circulation. According to one of them, the foreign sciences never ceased to be viewed by the great majority of Muslims as useless, alien, and perhaps dangerous. They went against the grain of orthodox thought, met no fundamental need, and were excluded from the developing educational system. As a result, the foreign sciences were never deeply integrated into Islamic culture, but survived on the margins. The undeniably great achievements of Islamic scientists and natural philosophers, therefore, must have emanated from isolated enclaves of scholars protected from the pressures of orthodoxy (as at a royal court during a period of unusual tolerance) or willing, for reasons known only to themselves, to swim against the cultural stream. This has been called the "marginality thesis," because of its claim that science in Islam was never more than a marginal pursuit.[12]

The alternative theory views the Islamic encounter with Greek learning in a quite different light. While acknowledging that suspicion and hostility existed, this theory maintains that on the whole Greek science and natural philosophy enjoyed a reasonably hospitable reception in Islam. After all, Islam did not reject the fruits of foreign learning but, despite conservative opposition, undertook a remarkable program of recovery and cultivation. Moreover, one can point to many examples of the integration of Greek disciplines into traditional learning and Islamic culture more generally. Thus logic became incorporated into theology and law; astronomy became an indispensable tool for the *muwaqqit,* who was responsible for determining the times of daily prayer in his locale; and mathematics became essential for a wide variety of commercial, legal, and governmental purposes. That mathematics and astronomy were occasionally taught in the most highly developed of the Muslim schools, the *madrasahs* or colleges of law, testifies to the high level of acceptance and integration. According to this interpretation, Islam successfully appropriated large portions of foreign learning, despite opposition; let us call this the "appropriation thesis." On this view, the foreign sciences did not conquer the traditional disciplines, but made peace with them by agreeing to serve as their handmaidens.[13]

The gap between these two interpretations is substantial; and, given the current state of research on the history of Islamic science, the dispute does not seem likely to be soon resolved. But several things can be said, which may help to mediate between the two positions. First, we must acknowledge that the marginality thesis in its strong form is untenable. The cultivation of Greek natural philosophy and mathematical science was far too widespread and successful to be viewed as a marginal product of Islamic culture. But while granting this to the "appropriationists," we must go on to point out that science was far from central to Islamic culture and that there were forces within Islam tending to marginalize the foreign sciences—which is to say that the "marginalists" have their eye on some genuine feature of Islamic culture. To be specific, Greek learning never found a secure institutional home in Islam, as it was eventually to do in the universities of medieval Christendom. One reason why this was so, is that Islamic schools lacked the structure and uniformity of those in the West, particularly at the higher levels.[14] This lack of structure offered freedom to the individual scholar to pursue whatever specialty he wished. Freedom insured diversity and created room for the practitioner of Greek philosophy and science; but it also insured that Islamic schools would never develop a curriculum that systematically taught the foreign sciences. In short, Islamic education did nothing to prohibit the foreign sciences; but neither did it do much to support them. This fact may help us to understand the decline of Islamic science in the thirteenth and fourteenth centuries.

THE ISLAMIC SCIENTIFIC ACHIEVEMENT

Early in the twentieth century, the distinguished physicist-philosopher-historian Pierre Duhem threw out a challenge for historians of Islamic science when he wrote: "There is no Arabian [read "Islamic"] science. The wise men of Mohammedanism were always the more or less faithful disciples of the Greeks, but were themselves destitute of all originality."[15] Duhem was clearly wrong, but his statement is useful nonetheless as a means of focusing our attention on the critical issue: by seeing precisely what is wrong with Duhem's claim, we stand to learn something important about the character of the Islamic scientific achievement.

It is simply not true that Muslim practitioners of Greek science were "destitute of all originality"; and one possible response to Duhem, therefore, is to demonstrate this by enumerating the many original contributions of Islamic physicians, mathematicians, and natural philosophers. To offer but a single example, the eleventh-century Muslim Ibn al-Haytham turned his critical powers on nearly the whole of the Greek scientific achievement and made contributions of the utmost importance and originality to astronomy, mathematics, and optics. Unfortunately, to carry out this program of recounting Muslim contributions to the various sciences would require volumes, and we must be content with more modest goals—though we will, below and in subsequent chapters, deal with Islamic contributions to certain specific areas of scientific discourse.[16]

But Duhem's statement offers us another point of entry into the problem, which may lead us to the central issue. Duhem maintains that Muslim scholars interested in the foreign sciences "were always the more or less faithful disciples of the Greeks." He says this with derogatory intent, as proof that the Muslims were not genuine scientists; that is, he associates discipleship with an unscientific attitude (which tells us something about his definition of science). However, we can turn Duhem's point around and argue that it was precisely by becoming the disciples of the Greeks that Muslims entered the Western scientific tradition and became scientists or natural philosophers. Discipleship, on this view, is essential, rather than antipathetic, to the scientific enterprise; and Muslims became scientists not by repudiating the existing scientific tradition, but by joining it—by becoming disciples of the most advanced scientific tradition that had ever existed.

What does it mean to be a disciple? For would-be Muslim scientists, it meant adopting both the methodology and the content of Greek science. By and large, Islamic science was built on a Greek foundation and carried out according to Greek architectural principles; Muslims did not attempt to pull down the Greek edifice and begin from the ground up, but applied themselves to completing the Greek project. This does not mean that originality and innovation were absent; it means that Muslim scientists expressed originality and innovation in the correction, extension, articulation, and application of the existing framework, rather than in the creation of a new one. If this seems to be a damning admission, let it be understood that the great bulk of modern science consists in the correction, extension, and application of inherited scientific principles; a fundamental break with the past is approximately as exceptional today as it was in medieval Islam.

Muslim scientists were aware of this relationship to the past. An early Muslim scientist, al-Kindī (d. ca. 866), who pursued the mathematical sciences under several early ʿAbbasid caliphs in Baghdad, acknowledged his debt to ancient predecessors and his membership in an ongoing tradition. Had it not been for the ancients, al-Kindī wrote,

> it would have been impossible for us, despite all our zeal, during the whole of our lifetime, to assemble these principles of truth which form the basis of the final inferences of our research. The assembling of all these elements has been effected century by century, in past ages down to our own time.

Al-Kindī conceived his obligation to be the completion, correction, and communication of this body of ancient learning. He continued:

> It is fitting then [for us] to remain faithful to the principle that we have followed in all our works, which is first to record in complete quotations all that the Ancients have said on the subject, secondly to complete what the Ancients have not fully expressed, and this according to the usage of our Arabic language, the customs of our age, and our own ability.

Two hundred years later al-Bīrūnī (d. after 1050) could still judge that the task facing Muslim scientists was "to confine ourselves to what the ancients have dealt with and endeavor to perfect what can be perfected."[17]

Islamic astronomy is a good illustration of the relationship between Islamic and Greek science. Muslim astronomers produced a great deal of very sophisticated astronomical work. This work was carried out largely within the Ptolemaic framework (though we must acknowledge early Hindu influences on Islamic astronomy, largely displaced by subsequent access to Ptolemy's *Almagest* and other Greek astronomical works). Muslim astronomers sought to articulate and correct the Ptolemaic system, improve the measurement of Ptolemaic constants, compile planetary tables based on Ptolemaic models, and devise instruments that could be used for the extension and improvement of Ptolemaic astronomy in general.

To give but a few examples, al-Farghānī (d. after 861), an astronomer employed at the court of al-Maʾmūn, wrote an elementary, nonmathematical textbook of Ptolemaic astronomy, which had wide circulation in Islam and (after translation into Latin) in medieval Christendom. Thābit ibn Qurra (d. 901), another court astronomer in Baghdad, studied the apparent motions of the sun and moon on Ptolemaic principles; he concluded that the precession of the equinoxes is nonuniform and devised a theory of variable precession (called "trepidation") to account for it. Al-Battānī (d. 929) introduced mathematical improvements into Ptolemaic astronomy, studied the motion of the sun and moon, calculated new values for solar and lunar motions and the inclination of the ecliptic, discovered the movement of the line of apsides of the sun (the shifting of the sun's perigee, or closest approach to the earth, in the heavens), drew up a corrected star catalogue, and gave directions for the construction of astronomical instruments, including a sundial and a mural quadrant. The fact that al-Battānī was still being cited in the sixteenth and seventeenth centuries (by Copernicus and Kepler, among others) testifies to the quality of his astronomical work. Finally, Islam saw a debate between defenders of the physically oriented concentric spheres of Aristotle and the mathematically oriented Ptolemaic system; this debate, conducted mainly in twelfth-century Spain, ended indecisively.[18]

Optics is another example of distinguished scientific achievement in Islam. Here we find innovations at least as fundamental as those in astronomy—innovations, nonetheless, that grew out of the reconciliation and consolidation of a variety of ancient traditions. To be specific, Ibn al-Haytham (d. ca. 1040), who served at the court in Cairo (where a separatist Muslim dynasty had established its own caliphate), followed Ptolemy's lead in combining what had originally been separate Greek approaches to optical phenomena—mathematical, physical, and medical. In the case of Ibn

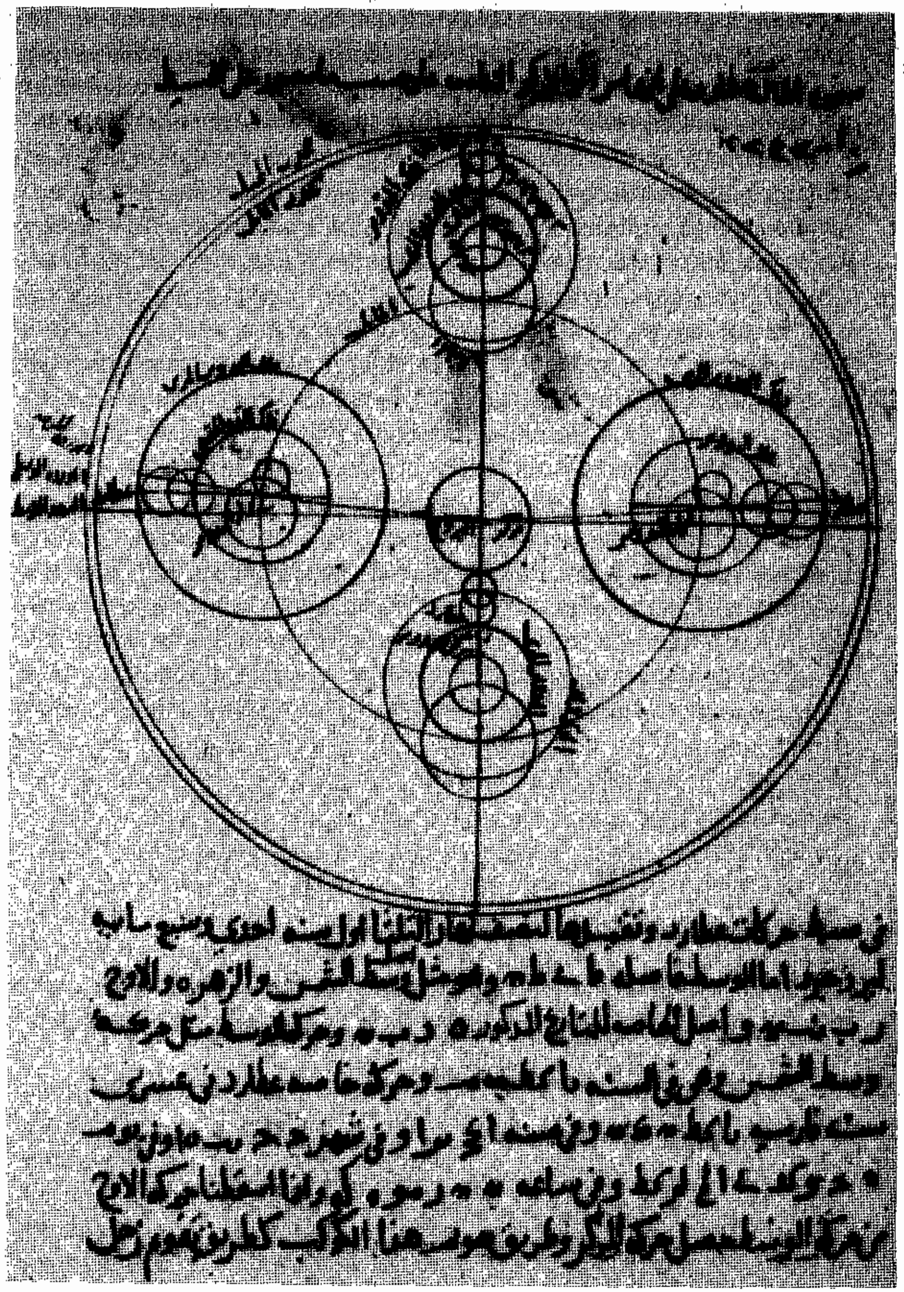
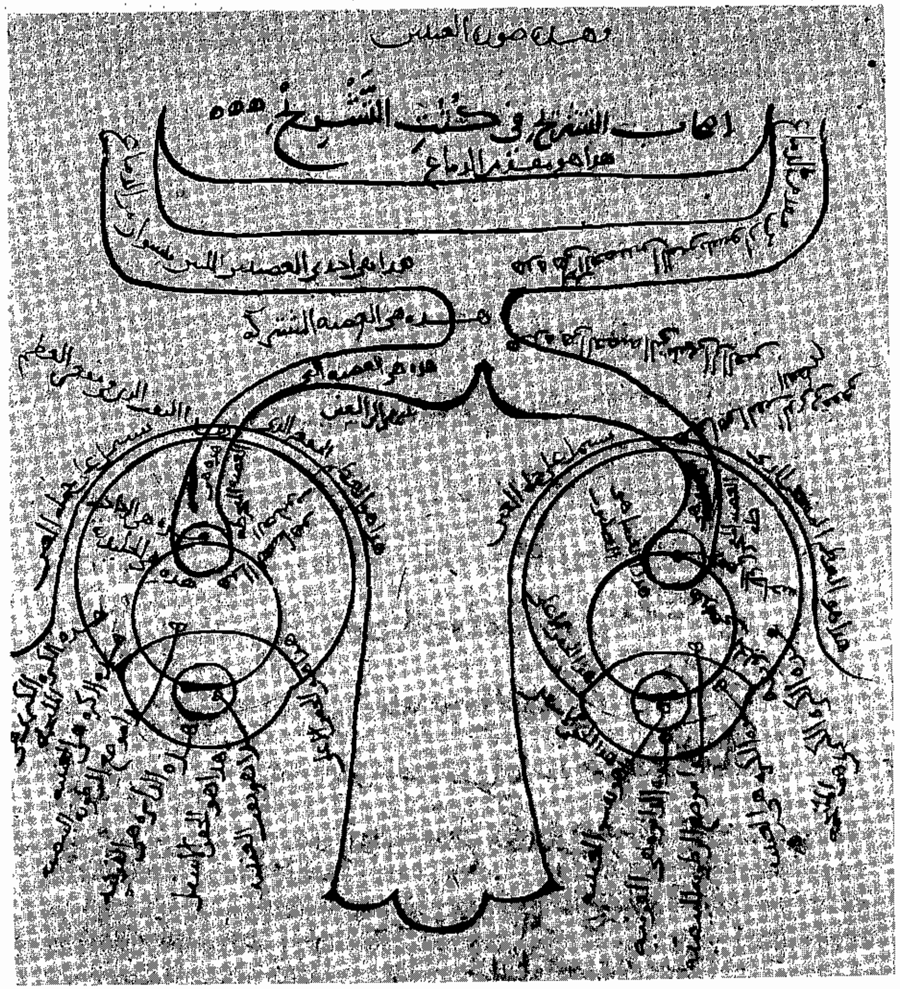


Fig. 8.3. The motion of Mercury according to Ibn ash-Shātir (14th c.). Oxford, Bodleian Library, MS Marsh 139, fol. 29r.

Fig. 8.4. The eyes and visual system according to Ibn al-Haytham. From a copy of al-Haytham's *Book of Optics* made in 1083 A.D., Istanbul, Süleimaniye Library, MS Fatih 3212, vol. 1, fol. 81v.



al-Haytham, this synthesis produced a new theory of vision, built on the idea that light is transmitted from the visual object to the eye, which was to prevail first in Islam and then in the West (see chap. 12, below) until Kepler devised the theory of the retinal image in the seventeenth century.[19]

THE DECLINE OF ISLAMIC SCIENCE

The scientific movement in Islam was both distinguished and durable. Translation of Greek works into Arabic began in the second half of the eighth century; by end of the ninth century translation activity had crested, and serious scholarship was under way. From the middle of the ninth century until well into the thirteenth, we find impressive scientific work in all the main branches of Greek science being carried forward throughout the Islamic world. The period of Muslim preeminence in science lasted for five hundred years—a longer period of time than has intervened between Copernicus and ourselves.

The scientific movement had its origins, for practical purposes, in Baghdad under the ʿAbbasids, though there came to be many other Near Eastern centers of scientific patronage. Early in the eleventh century, Cairo, under the Fatimids, came to rival Baghdad. In the meantime, the foreign sciences had made their way to Spain, where the Umayyads, displaced in the Near East by the ʿAbbasids, built a magnificent court at Cordoba. Under Umayyad patronage, the sciences flourished in the eleventh and twelfth centuries. Instrumental in this development was al-Ḥakam (d. 976), who built and stocked an impressive library in Cordoba. Another large collection of scientific books was to be found in Toledo.

But during the thirteenth and fourteenth centuries, Islamic science went into decline; by the fifteenth century, little was left. How did this come about? Not enough research has been done to permit us to trace these developments with confidence, or to offer a satisfactory explanation, but several causal factors can be identified. First, conservative religious forces made themselves increasingly felt. Sometimes this took the form of outright opposition, as in the notorious burning of books on the foreign sciences in Cordoba late in the tenth century. More often, however, the effect was subtler—not the extinction of scientific activity, but alteration of its character, by the imposition of a very narrow definition of utility. Or to reformulate the point, science became naturalized in Islam—losing its alien quality and finally becoming Islamic science, instead of Greek science practiced on Islamic soil—by accepting a greatly restricted handmaiden role. This meant a loss of attention to many problems that had once seemed important.

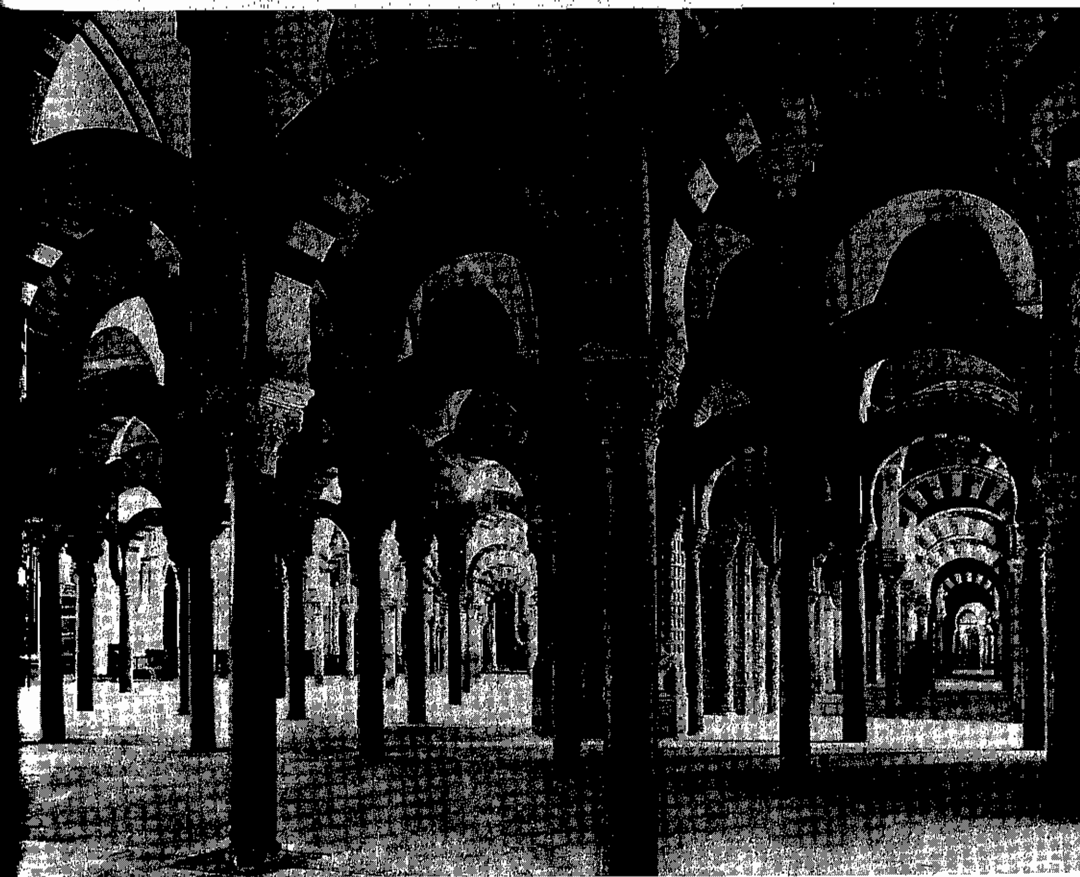


Fig. 8.5. Interior of the Great Mosque of Cordoba, built in the middle of the 8th century A.D. Foto Marburg/Art Resource NY.

Second, a flourishing scientific enterprise requires peace, prosperity, and patronage. All three began to disappear in late medieval Islam as a result of continuous, disastrous warfare among factions and petty states within Islam and attack from without. In the West, the Christian reconquest of Spain began to make serious, if sporadic, headway after about 1065 and continued until the entire peninsula was in Christian hands two centuries later. Toledo fell to Christian arms in 1085, Cordoba in 1236, and Seville in 1248. In the east, the Mongols began to apply pressure on the borders of Islam early in the thirteenth century; in 1258 they took Baghdad, thus bringing the ʿAbbasid caliphate to an end. In the face of debilitating warfare, economic failure, and the resulting loss of patronage, the sciences were unable to sustain themselves. In assessing this collapse, we must remember that at an advanced level the foreign sciences had never found a stable institutional home in Islam, that they continued to be viewed with suspicion in conservative religious quarters, and that their utility (especially as advanced disciplines) may not have seemed overpowering. Fortunately, before the products of Islamic science could be lost, contact was made with Christendom, and the process of cultural transmission began anew.