The world of ISLAM

FAITH · PEOPLE · CULTURE

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MAZİNİN ŞANI ÂTİNİN VAADİ

ENDPAPERS: declarations of faith are themselves part of the pattern on this detail from a sepulchral silk cloth. Four pious legends are rendered in yellow and blue: the vigorous larger Naskhī script gives two sentences – ‘Call ʿAlī the source of all wonders’ and ‘Assistance and victory come from God’ – and the finer Nastaʿlīq script repeats: ‘In the name of God, the Merciful’, and ‘Assistance comes from God, and the victory is at hand.’ This work, from Kāshān in Persia, was executed in 1053/1643 as a bequest to a holy shrine. It also includes the names of the donator, the calligrapher and the artist who made it. Photo: David Collection, Copenhagen.

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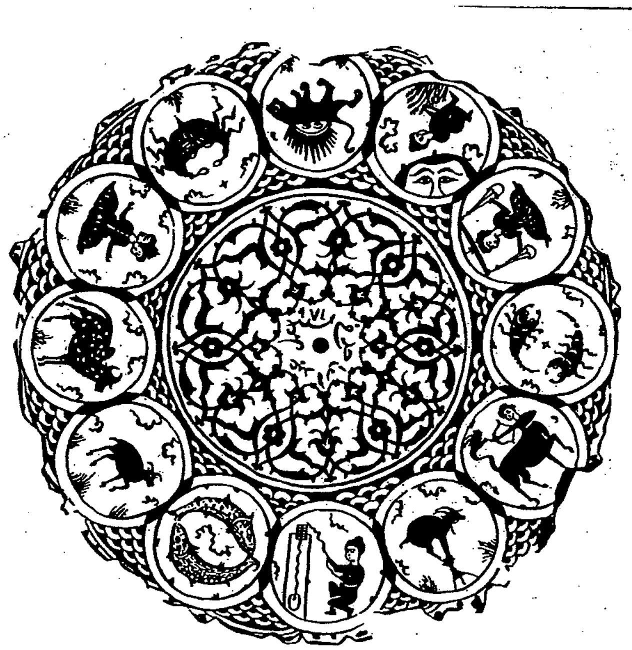
Chapter Seven

THE SCIENTIFIC ENTERPRISE

A. I. Sabra



Islamic science was essentially a development of Greek theory and research. This Persian plate, dated 971/1563, shows the signs of the Zodiac in forms very close to their Greek originals. (1)

181-28

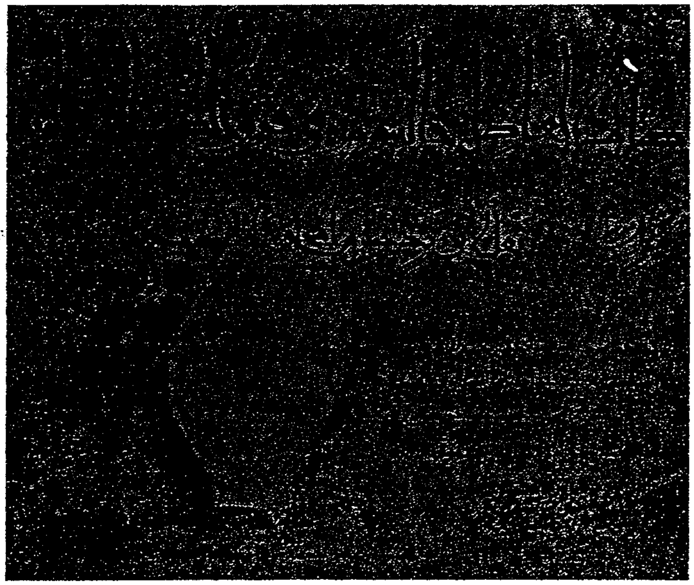
A STORY FROM THE IV/10th CENTURY offers an explanation of the rise of science and philosophy in Islam: it all started with a dream which the ʿAbbāsid Caliph al-Maʾmūn (198–218/813–33) had. There appeared to him, sitting on a couch, a man with a fair and ruddy complexion, a broad forehead, joined eyebrows, a bald head, light-blue eyes and a pleasing appearance. Filled with awe, the Commander of the Faithful asked: 'Who are you?' 'Aristotle,' the man replied. Delighted with the answer, and being granted to ask further questions, al-Maʾmūn came out with the all-important question: 'What is good?' 'That which is good in the mind,' replied Aristotle. 'And what comes next?' 'That which is good in the Law.' 'Then what?' 'That which is considered good by the people.' Finally Aristotle advised al-Maʾmūn that he should treat as gold whoever advised him about gold (alchemy) and he should hold to the doctrine of *tawhīd*, or Oneness of God. It was in consequence of this dream, so goes the story of the bibliographer Ibn an-Nadīm, that al-Maʾmūn determined to seek the books of ancient philosophers and have them translated into Arabic.

The appropriation of ancient learning

The story appears to link al-Maʾmūn's official support for the Muʿtazilīs, who insisted on a primary role for reason in matters of religious dogma, with his well-known efforts to disseminate the sciences of the Greeks among Muslims. The Muʿtazilīs were called the *ahl at-tawhīd*, the upholders of the doctrine of the Oneness of God, in consequence of their particular stand on the issue of God's attributes. Their position became epitomized in the doctrine of the createdness of the Qurʾān as the Word of God, which al-Maʾmūn sought to force upon unsympathetic Traditionists and legists, thus initiating the Inquisition which in the time of his successor al-Muʿtasim (218–28/833–42) led to the persecution of Ahmad ibn Hanbal, the highly esteemed Traditionist and founder of a strict legal school that had no use for rational argumentation.

Al-Maʾmūn was probably not the founder of the government-supported Library in Baghdad which quickly became the centre of translation into Arabic; but it was in his reign that the Library, under the name of the Bayt al-Hikma, or Institute of Science, perhaps reached the highest point in its career. Tradition has it that al-Maʾmūn, like al-Mansūr (138–9/754–5) and ar-Rashīd (170–94/786–809) before him, obtained from Byzantium Greek scientific and philosophical books which he subsequently ordered to be translated. Another collection is said to have come to him from Cyprus. Such collections had in fact been gradually gathered from as far back as the end of the Umayyad period, when the process of translation had already begun. It does appear, however, that translation at Bayt al-Hikma, in the time of al-Maʾmūn, became a well-organized activity of unprecedented scope and vigour. Translators worked in groups, each supervised by an expert and assisted by copyists. Works translated from Syriac were checked against the Greek originals when possible. And Arabic translations from Greek were revised in the light of newly acquired manuscripts. Al-Maʾmūn can truly be said to have given great impetus to the movement which was soon to bring the bulk of Greek science and philosophy within reach of a large number of Arabic-reading scholars. And his personal interest in the translation activity may well have been connected with his sympathy for the rationalizing Muʿtazilīs.

The translation work which began in the second half of the II/8th century was practically done by the end of the IV/10th, never to be taken up again on any significant scale in the Islamic Middle Ages. A brief look at a few of the translators reveals something of the ethnic and religious variety they displayed and the degree to which the political establishment was involved in promoting their work. Some of them were Persians, like the astrologer Ibn Nawbakht, who was making translations for ar-Rashīd from Pahlavī into Arabic. Al-Fazārī, whom al-Mansūr ordered to work with an Indian from Sind on the translation of the astronomical *Sindhind* from Sanskrit, was of Arab descent. The most active translator of medical works from Greek and Syriac, the celebrated Hunayn ibn Ishāq (d. 260/873), was a Nestorian Christian from al-Hīra. Possibly in connection with Bayt al-Hikma during the reign of al-Maʾmūn, and continuing until the time of al-Mutawakkil, whose personal physician he



Detail from the first page of 'The book of the excellent Galen On Medical Sects for Students', *translated by Abū Zayd Hunayn ibn Isḥāq the physician. This page is especially interesting because it is annotated by two former owners, one of them none other than Avicenna. His note is on the right, just under the main heading, and reads: '[Came] into the possession of Husayn ibn 'Abdallāh ibn Sīnā the physician in the year 407' (i.e. 1016–17). The second note is bottom right and reads: '[Came] into the possession of Jibrā'īl ibn Bakhtīshū', the Christian physician.' Jibrā'īl is known to have died in 214/828. (2)*

became, Hunayn brilliantly led a team of translators who rendered into Arabic the works of Hippocrates and Galen. His son and pupil Ishāq (d. 299/911), who, like his father, knew Greek, translated philosophical works by Aristotle, the *Elements* of Euclid and Ptolemy's *Almagest.* Thābit ibn Qurra (d. 281/901), a member of the pagan community at Harrān, was a distinguished mathematician and astronomer who worked on the translation of mathematical works from the Greek. He was introduced to the court of the Caliph al-Mu'tadid (279–90/892–902) by one of the sons of Mūsā ibn Shākir, 'the Astrologer'. The three sons of Mūsā, Muhammad, Ahmad and al-Hasan, had as young men been protégés of al-Ma'mūn and later became noted for their persistent efforts to obtain books from Byzantium, and for their encouragement and generous financial support of the translation activity, in addition to their own work in mathematics and mechanics.

It is easy to think of reasons why members of the ruling class wanted to surround themselves with future-telling astrologers and health-preserving physicians. It is also true that Muslims in all parts of the Muslim world were in need of mathematically educated persons who would be able to determine the astronomically defined times of prayer and the direction of Mecca. A large mass of literature, much of which is hackneyed – though some of which is quite ingenious – and the apparently wide-scale production of portable instruments (such as astrolabes and quadrants) for the determination of time, can be accounted for in terms of these needs. But the enterprise of Islamic science and philosophy, with its high level of achievement and its marked interest in theoretical and abstract questions, can hardly be explained as the unintended consequence of the practical concerns of a few individuals, however powerful and influential. In Islam, as in other civilizations, nothing less profound than genuine curiosity, or less complicated than the interplay of social, cultural and deep human needs, can suffice to explain such an impressive and long-lasting enterprise.

To a large extent, Islamic science was a continuation of an already existing though waning Greek tradition: Baghdad was heir to an Alexandrian school which had been drawn to it after journeying through Antioch and Harrān. Another formative influence came from Jundīshāpūr, in south-west Iran, where a medical school had flourished for a long time. Nestorians, who originally sought refuge there after they had been expelled from Urfa (Edessa) in 489, taught Greek medicine in Syriac and Persian translations. A new influx of Greek ideas came with the arrival of Neo-platonic philosophers after the closing of their school at Athens in 529. At the time of Anūshirwān (531–79) the city of Jundīshāpūr became an active centre of learning in which Greek, Persian, Syriac, Jewish and Indian ideas intermingled. All of these elements were to exert a profound influence on Islamic intellectual life from the beginning of the 'Abbāsid period. The head of the medical school at Jundīshāpūr, the Nestorian Jibrā'īl ibn Bakhtīshū', was called to Baghdad in 148/765 where he became court physician to the Caliph al-Mansūr. During the reign of Hārūn ar-Rashīd, Jibrā'īl was charged with building a Bīmaristān or hospital at Baghdad after the Syro-Persian model already established at Jundīshāpūr, and this copy again became the prototype of many hospitals subsequently built at Baghdad and elsewhere. Jibrā'īl returned to Persia a year or two before he died, but other members of the Bakhtīshū' family remained in the service of the 'Abbāsids for a long time.

Arabic scientific geography began with the translation of non-Arabic texts at the beginning of the 'Abbāsid rule. As in the case of Arabic astronomy, the sources of Arabic geography were various: Indian and Persian as well as Greek. But it was again the Greek influence, exerted mainly through the works of Ptolemy and Marinus of Tyre, that became predominant. Following the Greeks the Arabs generally divided the inhabited world into seven climes represented by circles parallel to the equator and to the north of it, and divided the climes longitudinally into ten sections. This became the authoritative framework into which all geographical information, both old and new, had to be fitted.

The work of al-Idrīsī, produced in the VI/12th century under the title *Kitāb Nuzhat al-mushtāq fī ikhtirāq al-āfāq,* is a good illustration of this tendency. As a scholar in the service of Roger II, the Norman King of Sicily, he was commissioned to prepare a geographical survey of the world with separate maps for all the climatic sections. This was a collaborative effort, and with the help of technicians and other scholars at Roger's court a large planispheric silver relief map was constructed which incorporated information derived from travellers as well as from Greek and earlier Arabic sources.

Despite the continuity with earlier traditions in which Greek learning had played a predominant role, historians have rightly emphasized the novelty of the scientific enterprise that was launched at Baghdad. For the first time in history, science became international on a really wide scale; and one language, Arabic, became its vehicle. A large number of scholars belonging to different nations and professing different beliefs collaborated in the process of moulding into this one language materials which had previously existed in Greek, Syriac, Persian or Sanskrit. It is this enduring character of the scientific enterprise in medieval Islam which is being emphasized when the phrase 'Arabic science' is used.

The opposition

The sciences imported mainly from Greece were bound to meet with opposition from various quarters. From the time when the translation movement began to the end of the Islamic Middle Ages, these sciences were either frowned upon or openly attacked by practitioners of the indigenous religious and Arabic disciplines. Grammarians rejected the claim of the teachers of Aristotelian logic that they were the sole arbiters of sound discourse; legists were unwilling to see their newly found forms of argument being refashioned in foreign moulds; and the adherents of the religious science of *kalām*, who were developing a whole world-view of their own, had no use for the peripatetic and Neo-platonic doctrines current among the *falāsifa* (sing. *faylasūf*) or followers of Greek philosophy. The 'foreign sciences', which included not only mathematics, astronomy and medicine, but also magic, alchemy and astrology, were generally felt by pious people to constitute a serious threat to religious beliefs and the values of religious life.

An exaggerated role has often been assigned to al-Ghazālī in the history of this conflict. This greatly influential religious thinker and spokesman for a mystical version of Sunnī (orthodox) Islam (he died in 505/1111) ot only wrote a well-argued refutation of philosophy, out repeatedly warned against exposing Muslims to potentially misleading though essentially innocuous rational sciences. Historians have sometimes viewed the conflict simply as an orthodox reaction, and by emphasizing the negative act of rejection, they have turned attention away from what still remains in need of explanation: the fact that science and philosophy continued to exist and develop in Islam for many centuries, despite the uninterrupted opposition.

Rather than being a marginal phenomenon, the enterprise of science and philosophy in Islam presents the historian with a real paradox. It would have been only natural for the self-confident Muslims from Arabia to launch an assault against vestiges of the pagan culture which they encountered in the conquered lands. The legend of the burning of the library of Alexandria by the Arab invaders, which was invented by a zealous Muslim at the time of the Crusades, has largely gained in plausibility from the expectedness of the alleged event. Nor would it have been surprising if the early Muslims had stood aloof from the activities of the Hellenized Christians and the Sabians. What those early Muslims did, however, was quite different and unexpected. Rather than suppress the declining Greek intellectual tradition, they sought out its sources and encouraged its cultivation. Theirs was not primarily an attitude of rejection or even of mere toleration, but of protectiveness and active participation. The foreign sciences of the Greeks could have lived as long and developed as much as they did in Islam only because of continued positive interest and support. To characterize their status in Islamic civilization as marginal would merely serve to relieve us from the task of explaining their existence.

The paradox is heightened by the fact that the philosophical and scientific disciplines were largely kept out of those institutions of learning, the *madrasas*, which were established primarily for religious education and which admitted the linguistic disciplines as a necessary adjunct to the study of the Qur'ān, the Traditions and the Law. Medicine was taught as well as practised in generously endowed Bīmaristāns or hospitals, and students of law were able and often required to learn some mathematics in the *madrasas* and in the mosques. But these observations do not adequately explain the high level of scientific and mathematical sophistication that was achieved in the works of Islamic scientists from the III/9th to the IX/15th century. It is, for example, clear from the output of able mathematicians from that whole period that their education in the mathematical and neighbouring fields, far from being elementary or spotty, was well-organized and wide-ranging. It is as though they had gone through a systematic course of study. A strong tradition of teaching the foreign sciences in Islam must have existed for many centuries, even though we do not know the full details of how it worked. That this tradition existed largely as a private institution does not diminish its importance.

The attitude of orthodox religious thinkers towards the sciences of the ancients was more complex than is usually assumed. Al-Ghazālī, who has often been blamed for the decline of science and philosophy, firmly believed and repeatedly declared that the study of the religious sciences of *kalām* and jurisprudence must be preceded by a sufficient grounding in Greek logic. He understood logic to be no more than a useful instrument for laying down rules of correct definitions and inferences. But by admitting Aristotelian logic into the curriculum of religious learning he opened the door for deeper penetration by other parts of Aristotelian philosophy into the various religious disciplines. The historian Ibn Khaldūn (d. 809/1406) has remarked, for example, that, as a result of the writings of al-Ghazālī and those of Fakhr ad-Dīn ar-Rāzī (d. 606/1209), it had become difficult in his own time to distinguish between a work on *kalām* and a work on philosophy.

Al-Ghazālī's attitude was in sharp contrast to that of the Hanbalī jurist Ibn Taymiyya (d. 729/1328), who launched a vehement and uncompromising attack on Greek logic. Unlike al-Ghazālī, he considered the whole system of Aristotelian logic to be based on a metaphysical doctrine which threatened the Islamic world-view; and he regarded the Aristotelian forms of argument as inimical to Islamic modes of thinking. It would, however, be wrong to conclude that a necessary connection existed between a strict view of Islam and such extremist views as those of Ibn Taymiyya. The Spanish thinker Ibn Hazm, for example, vigorously maintained a literalist view of Islamic law, but he was no enemy of Greek logic and even composed an introductory account of it. In any case, it was al-Ghazālī's view, and not that of Ibn Taymiyya, which has prevailed in important centres of Muslim education, such as the Azhar University in Cairo, where Aristotelian logic has continued to be taught up till now.

On the threshold of Islamic science and philosophy stands the unexpected figure of Yaʿqūb ibn Isḥāq al-Kindī (d. *c.* 257/870). A Muslim and a member of the Arab aristocracy (his family descended from the kings of the ancient south Arabian tribe of Kinda and his father had held the high position of governor at Kūfa), he set up himself as a propounder of the Greek scientific and philosophic tradition which in his time was identified mainly with non-Muslims and non-Arabs. 'We should not be ashamed,' he wrote, 'to acknowledge truth and to assimilate it from whatever source it comes to us, even if it is brought to us by former generations and foreign peoples.' And further: 'My principle 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 custom of our age and our own ability.' Writing as a Muslim who addressed himself to a Muslim audience, he laid the foundations of Islamic philosophy by taking the first significant steps in the direction of reconciling Islamic doctrines with a Neoplatonic version of Greek philosophy. His philosophical system preserved such Islamic beliefs as the createdness of the world and the resurrection of the body, but he had no intention of downgrading the values of Greek philosophical thought to which he remained committed enough to deserve to be called a *faylasūf*, a philosopher in the sense of the Greek tradition. His espousal of Greek thought was uninhibited and all-embracing; he opened up his mind to astrology and alchemy, as well as to metaphysics, meteorology, optics, music and medicine. Al-Kindī depended on translations made by others who were learned in Greek or Syriac, but he was able to play a special role in bringing about the naturalization of the ancient sciences, both linguistically and intellectually. The results of his vigorous and whole-hearted efforts were far-reaching.

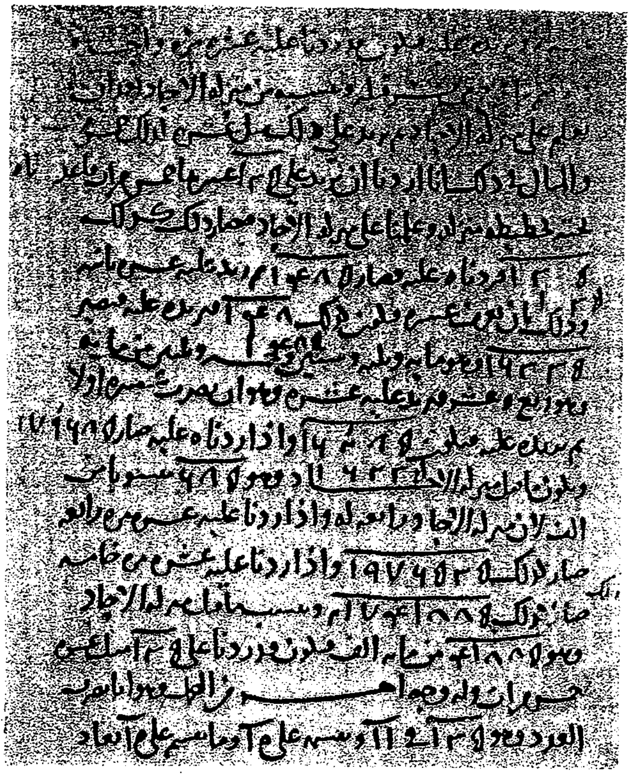
Later Islamic philosophers were frequently even more confident of their adopted values than al-Kindī, and sometimes went even further than he in their commitment to the aim and methods of Greek thought. For the most part they were neither meek nor secretive, as one might have expected from a 'marginal' group who felt themselves on the defensive. Al-Fārābī (d. 339/950) openly declared his conviction that the dialectical argumentation of Islamic theology was definitely inferior to the demonstrative methods of the *falāsifa*. Abū Bakr ar-Rāzī (d. *c.* 313/925), the philosopher-physician who aligned himself with Plato and Galen, held heretical views with regard to all revealed religions. And Avicenna's position on fundamental issues concerning God and His relation to the world was such as to bring down upon him the wrath of orthodox religious thinkers. It is true that for a long time philosophy remained on the defensive in the Maghrib and in Spain. And yet it was from the Cordoban Averroes that came the strongest rebuttal to al-Ghazālī's attack on philosophy. And there is evidence to suggest that in Averroes' time something like an alliance between the political establishment and philosophical élitism was being forged against the Mālikī jurists. In general physicians and mathematicians were not readily identified with views which injured the sensitivity of pious people. Frequently astronomers and physicians claimed that their work revealed evidence for the wisdom of God. At the same time, however, they were prone to look down on practitioners of the religious sciences for having substituted authority for genuine knowledge.

Innovation and tradition: mathematics

The finest treatise in Arabic arithmetic was written in the year 830/1427 in Samarqand – a time and a place far removed from ʿAbbāsid Baghdad where, in about 210/825, al-Khwārizmī composed probably the first Arabic compendium of Indian-type arithmetic. The author of that treatise, Jamshīd ibn Masʿūd al-Kāshī, was a Persian from Kāshān who had moved to Samarqand, where he secured a distinguished position among the group of astronomers and mathematicians patronized by the learned Sultan Ulugh Beg. Al-Kāshī's treatise, entitled *The Key to Arithmetic*, was a comprehensive, clearly written and well-arranged handbook intended for the use of merchants, clerks and surveyors, as well as theoretical astronomers. One of its notable contributions was its full and systematic investigation of decimal fractions which had made an appearance in Islam as early as the iv/10th century in the work of a Damascene arithmetician named al-Uqlīdisī. Al-Kāshī's novel treatment of the subject thus anticipated similar developments in Europe by about two hundred years. His *Key to Arithmetic* circulated widely in the Islamic world, its influence already reaching Constantinople in the second half of the ix/15th century. The occasional use of decimal fractions has been noted in a Byzantine document which made its way to Vienna in 970/1562.

Al-Kāshī's achievement in arithmetic was the culminating point in a series of developments in which the power of tradition seems often to have inhibited the will to innovation. The Islamic world had inherited three different systems of numerical calculation which were of different origins and which continued to exist side by side for many centuries. The first, of unknown origin, was called 'finger reckoning' because in performing its operations one retained the results of intermediate steps by holding one's fingers in certain positions. It was also called 'arithmetic of the scribes' (or secretaries). The title of a handbook of this type of arithmetic, written in Baghdad about 370/980 by Abū 'l-Wafā' al-Būzjānī, indicates that it was intended for the use of the government bureaucracy. The system in fact continued to be used by members of the secretarial class despite the existence of the much superior type of reckoning which had come from India in the ii/8th century or earlier, and on which many handbooks were available.

In the 'arithmetic of the secretaries', numbers were written out in words. Based on the place-value idea, the Indian system of reckoning was able to express any number, however large, with the help of only ten figures, including a sign for zero (*ṣifr*) which indicated an empty place. Medieval Arabic authors referred to these figures as 'Indian' or 'dust' numerals, thereby indicating their origin and the fact that the operations effected by their means were performed on a dust-board. In the Islamic world, Indian numerals existed in two forms, one in the east, the other in the west, and it was from the latter that medieval Europe derived its 'Arabic numerals'.



Decimal fractions first appeared in Arabic in the work of the IV/10th-century Damascene arithmetician Abū 'l-Hasan al-Uqlīdisī. This page from the unique manuscript of al-Uqlīdisī's Kitāb al-Fusūl *shows the decimal point as a stroke above the number in the units place in line 10. (3)*

Astronomers simply ignored the advantage of the Indian system of numeration. Continuing the tradition of Greek astronomical works, they adhered to the old Babylonian system in which letters of the alphabet stood for numbers. It was in fact a mixed system in which a non-place-value decimal notation was used for integers and a place-value sexagesimal system for fractions. This meant that in Islam the most sophisticated computations were performed in sexagesimals indicated by alphabetical symbols. Despite the apparent analogy between the decimal and sexagesimal systems, and although decimal fractions had already appeared in the iv/10th century, it was not until al-Kāshī's time that a unified place-value system was formulated for both fractions and integers.

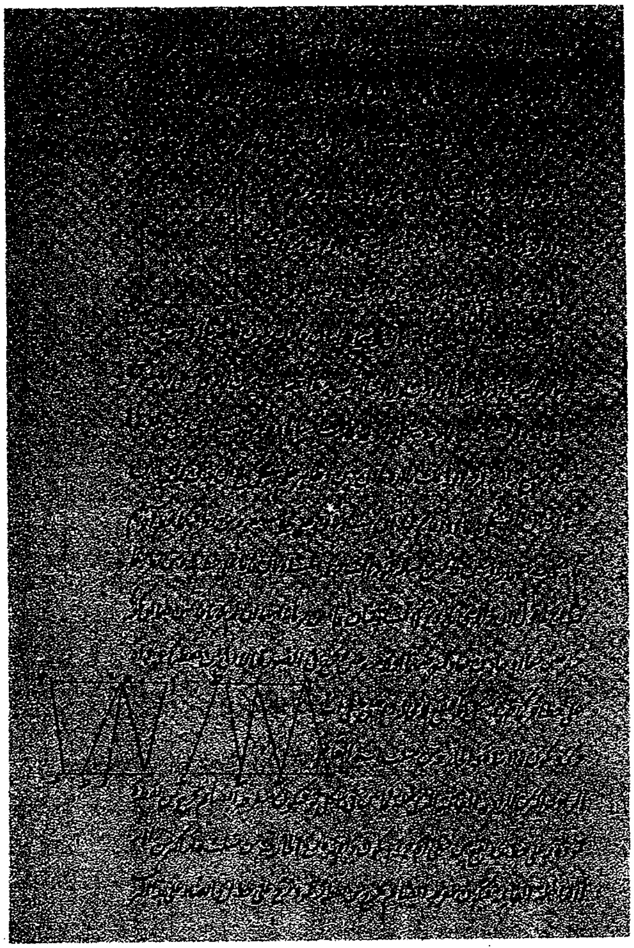
It is impossible to explain the character of Arabic mathematics (let alone Arabic science as a whole) in terms of such entities as the Arab or Islamic 'mind', or even the Arabic language, though attempts have been made in this direction. Not only in arithmetic, but also in geometry and algebra, much of the character of the Islamic products can readily be explained by reference to older traditions. Innovations of varying degrees of importance were bound to occur, and did occur, in all these fields. It may be interesting to view these developments against the background of a pervasive medium, such as the Arabic language, or a supposedly prevalent intellectual attitude, such as 'atomism', but this alone would be a poor substitute for real historical analysis.

The beginning of Arabic algebra may be taken as an example. The first Arabic treatise on this subject was written under al-Ma'mūn by Muhammad ibn Mūsā al-Khwārizmī. The question of his algebraic sources has been much debated. Some of his methods are anticipated in Indian and Babylonian records. His treatise did not use any symbolic notation, but, like all subsequent algebraic treatises in Arabic with the exception of one by al-Qalasādī (d. *c.* 891/1486), was entirely rhetorical. On the other hand, his geometrical proofs of algebraic procedures are Euclidean in character. The title of his treatise, *al-Jabr wa 'l-muqābala*, referred to the two operations used by him in the process of solving linear and quadratic equations, namely those of eliminating negative quantities and reducing positive quantities of the same power on both sides of the equation. It now appears that these terms, which may be translated as restoring (or completing) and balancing respectively, in fact rendered concepts already present in the work of Diophantus. And yet, no prototype of al-Khwārizmī's book as a whole is known to have existed in any language prior to the iii/9th century. Medieval Arabic authors classed al-Khwārizmī's treatise among those compositions which started something new. Its systematic approach, represented by its reduction of the treated problems to canonical forms provided with proofs, can be said to have impressed its character on subsequent algebraic works, even when these (like the treatises of al-Karajī and 'Umar Khayyām) went far beyond it.

No mystery surrounded Arabic geometry; it was Greek in origin, methods and terminology. Basing themselves on Euclid, Archimedes and Apollonius, Islamic mathematicians produced a large number of treatises in which they explained, developed or criticized the works of their Greek masters. Islamic civilization did not produce an Archimedes or a Leibnitz, but its better mathematicians mastered the higher techniques of the Greeks and were sometimes able to use them to formulate and solve new problems.

The *Elements* of Euclid received perhaps more attention than any other mathematical work from Antiquity. It was translated into Arabic under ar-Rashīd and again under al-Ma'mūn. Several versions of the *Elements*, called 'Recensions', were prepared at different times. These were textbooks in the best sense of the word, and often contained rearrangements or extensions of the Euclidean theorems. Investigations of Euclid's concepts of ratio and proportion, which were felt to be unsatisfactory, finally led Islamic mathematicians to a widened concept of number which included the irrational. Much of the credit for this development goes to 'Umar Khayyām and Nasīr ad-Dīn at-Tūsī. The definition of proportion utilized by these mathematicians is not that of Eudoxus and Euclid, but seems nonetheless to be of Greek origin.

Research into Euclid's theory of parallels is another example of the Islamic mathematicians' taste for foundational problems. Attempts to prove Euclid's parallels postulate have been found in Arabic writings dating from the iii/9th to the vii/13th century. The problem underlying these investigations had been pointed out in Antiquity. The Arabs inherited the problem; but rather than acquiesce in a ready-made solution, they pursued the search for ever better solutions. They did not finally propose a non-Euclidean system of geometry, but they formulated and proved some non-Euclidean theorems,



The problem of parallel lines, posed by Euclid's parallels postulate, received much attention from Islamic mathematicians throughout the history of medieval Arabic science. Naṣīr ad-Dīn aṭ-Ṭūsī's was probably the most mature treatment of the problem in Arabic, making use of Euclid's definition of parallel lines as non-secant lines and drawing on the results of his predecessors. The page from his ar-Risāla ash-Shāfiya *shows Ṭūsī's figure for proving 'Saccheri's hypothesis' of the right angles, which is equivalent to Euclid's postulate. (4)*

and one of their attempts to prove the postulate later became known to European mathematicians, who made notable contributions to the history of this problem, such as Wallis and Saccheri.

Applied mathematics

The idea of mechanics as applied mathematics was not foreign to Islamic civilization, being clearly implied in the works of Greek mechanicians, such as Hero of Alexandria and Philo of Byzantium, which became available in Arabic translations. The Greek concept of mechanical technology was often expressed in Arabic by the phrase *ʿilm al-ḥiyal*, or 'science of devices'. In his *Catalogue of the Sciences*, the philosopher al-Fārābī (d. 339/950) explicitly declares that the aim of this science is to determine the means by which those things whose existence is demonstrated in the various mathematical sciences can be applied to physical bodies. Elaborating this important idea, he explains that in order to produce the truths of mathematics artificially in material objects, the latter may have to be subtly altered and adapted. In this sense, the 'science of devices' is a general art which includes algebra (on this account a kind of applied arithmetic that seeks to determine unknown numerical quantities) as well as building, surveying, the manufacture of astronomical, musical and optical instruments, and the design of wondrous devices. All these and similar arts, says al-Fārābī, are principles of the practical crafts of civilization.

It is therefore worthy of note that many of the writers on mechanics, such as the Banū Mūsā, al-Bīrūnī, al-Karajī, ʿUmar Khayyām, Ibn al-Haytham, were distinguished mathematicians. But these were not entirely armchair mechanicians. The Banū Mūsā, whose work on mechanical devices is largely concerned with trick vessels, supervised various engineering projects for their patrons, the caliphs at Baghdad. Al-Bīrūnī made accurate determinations of specific gravities. Ibn al-Haytham had a scheme for regulating the flow of the Nile water. And so on.

The most important and most informative document on Islamic mechanical technology that has come down to us is a treatise written in the beginning of the VII/13th century by Ibn ar-Razzāz al-Jazarī. Entitled *The Book of Knowledge of Ingenious Mechanical Devices*, it presents itself as the work of a craftsman, not of a theoretical or mathematical mechanician. Written for the Artuqid prince of Diyārbakr Nāṣir ad-Dīn Maḥmūd, whom al-Jazarī served, it describes in great detail the construction of a large number of devices of a wide range which the author divided into five main categories: clocks of various kinds, vessels, measuring basins, fountains and water-raising machines.

Astronomy: theory and observation

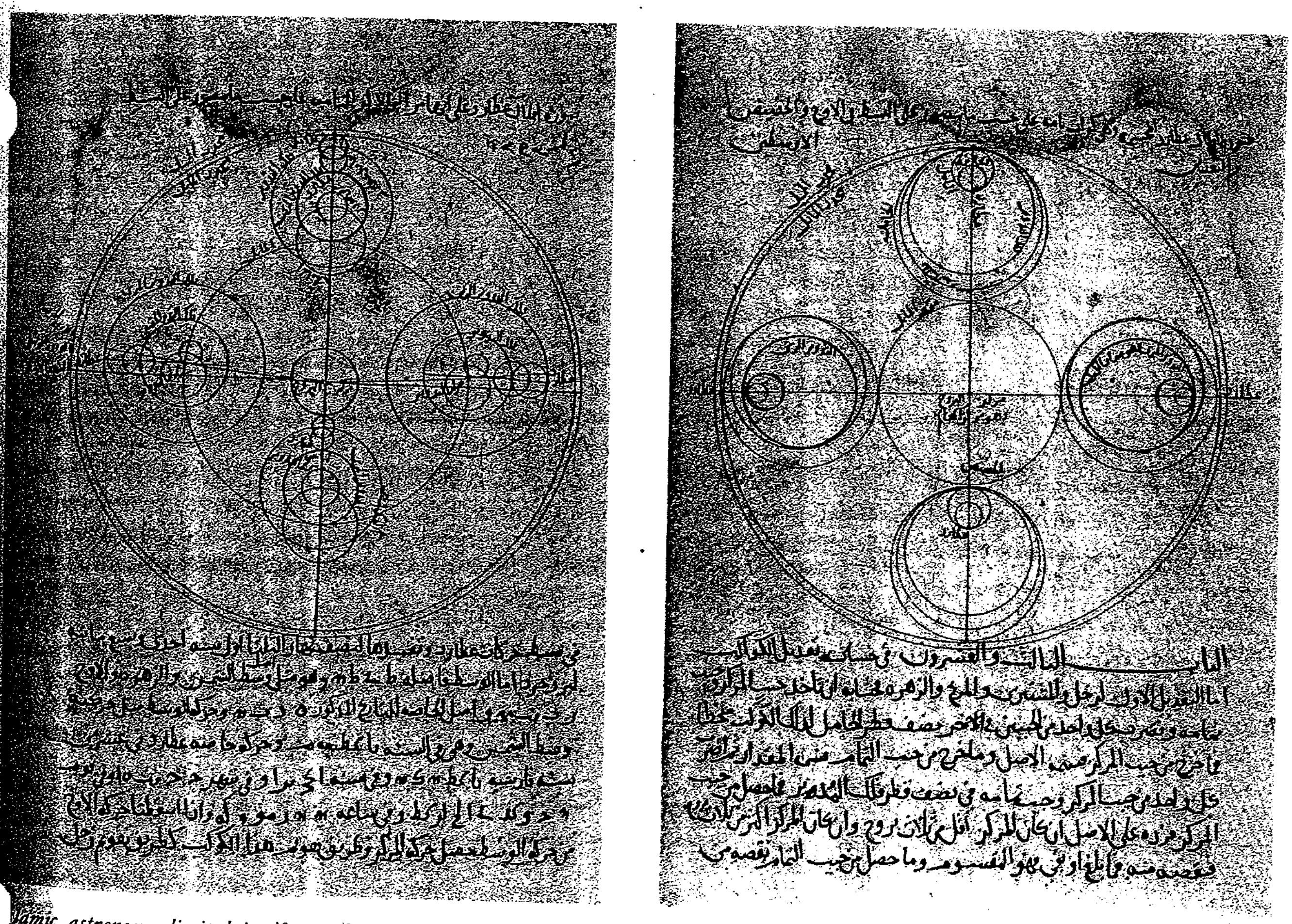
The general history of astronomy in medieval Islam exhibits a curious lack of interaction between theory and observation, though both of these were actively pursued. Observations, on the whole, had little impact on theoretical developments; and theoretical innovations were neither inspired by nor did they lead to novel observations. It is as if each of these two activities revolved within a limited sphere of its own.

Translations in astronomy were at first made from a variety of languages – from Sanskrit, Pahlavī and Syriac, as well as from Greek. The result was an eclecticism which marked the early productions of Arabic astronomy, and which also made a later appearance in Muslim Spain. After the translation of the *Almagest*, however, the superiority of Ptolemy's system was quickly recognized, and, from then on, Arabic astronomy remained predominantly Ptolemaic in conception and method.

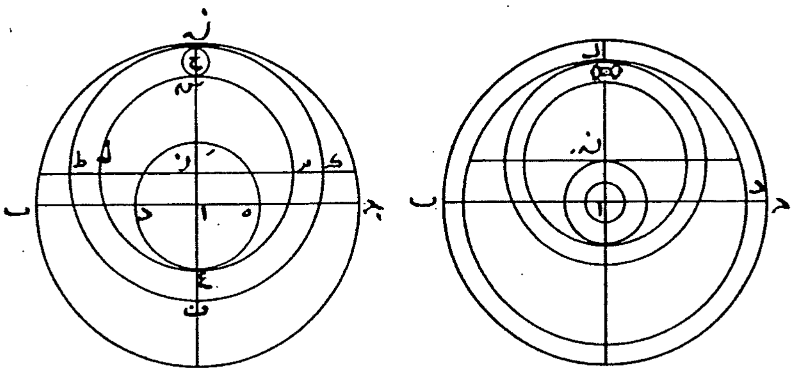
The Arabs inherited from Ptolemy a concept of testing which they constantly kept before their minds and frequently put into practice. In the beginning of the IV/10th century, the Harrānian astronomer al-Battānī, whose *az-Zīj as-Ṣābī* was modelled after the *Almagest*, ascribed to Ptolemy the 'injunction' that observations be made after him for the purpose of testing his own observations, just as he himself had made tests of the observations of his predecessors. This exhortation, which is in fact implicit in Ptolemy's book, was taken quite seriously by Islamic astronomers, and the words *miḥna* and *iʿtibār*, used by the translators of the *Almagest* to render the Greek concept of testing, can be seen almost everywhere in the medieval Arabic literature on astronomy. The lesson learnt from the example set by Ptolemy was assiduously applied. Throughout the history of Islamic astronomy, observations were made at various places and at various centres of astronomical research. Thus, during the reign of al-Ma'mūn a group of astronomers prepared a new set of tables or *zīj*, known as the *Ma'mūnī* or *Mumtahan* (tested) *zīj*, on the basis of new observations made at Baghdad and Damascus. Also under the ʿAbbāsids, Habash al-Hāsib made observations of solar and lunar eclipses and of planetary position at Baghdad, Samarra and Damascus. Ibn Yūnus (d. 400/1009) conducted observations at Cairo in the IV/10th century. At Shīrāz, beginning in the year 359/969, the famous as-Sūfī made a series of observations to determine the lengths of seasons. Towards the end of the IV/10th century, the great al-Bīrūnī was engaged in observations of lunar eclipses in Khwārazm. In the VII/13th century, astronomical observations were carried out for a continuous period of about twenty years at Marāgha, where Hülegü had built in 685/1259 an observatory in which a group of astronomers worked, headed by Nasīr ad-Dīn at-Tūsī. This may have been the first observatory in the full sense of the word. It had a staff of about twenty astronomers drawn from various parts of the Islamic world, including one from China; it was equipped with a library and in it instruments (quadrants, armillaries, astrolabes) were designed and constructed. In the first half of the IX/15th century Sultan Ulugh Beg founded an imposing observatory at Samarqand whose remains can still be seen.

Most of these observations had the limited aim of checking values received from different sources or improving the Ptolemaic parameters. They yielded, for example, new values for the inclination of the ecliptic, the rate of equinoctial precession, the mean motions of the sun, the moon and the planets and so on. This limitation cannot be ascribed to the instruments used, some of which (like those constructed by al-ʿUrdī at Marāgha) were sophisticated and capable of producing more significant results than those in fact obtained by their means. One is left with the impression that Islamic astronomers were engaged in correcting and re-correcting previous observations, rather than testing newly imagined hypotheses.

Not that new hypotheses were never invented. The astronomers at Marāgha, and later Ibn ash-Shātir at Damascus, produced non-Ptolemaic planetary models which have recently been compared with their counterparts in Copernicus. But these inventions were independent of observations, whether made at Marāgha or elsewhere, and the story of their coming into being must be told in quite different terms. The story seems to begin in the V/11th century when Ibn al-Haytham, the mathematician from Iraq who lived in Cairo at the time of the Fātimid Caliph al-Hākim (d. 412/1021), wrote an attack on Ptolemy's planetary theory. Ibn al-Haytham accepted



lamic astronomy limited itself to reforming Ptolemaic planetary heory rather than testing fundamentally new hypotheses. This reform, begun in the VII/13th century by Nasīr ad-Dīn at-Tūsī at Marāgha, ached its culmination in the work of the VIII/14th-century Damascene astronomer Ibn ash-Shātir. These two diagrams from Ibn ash-Shātir's Nihāyat al-sūl *illustrate the first successful representation of the motions of Mercury exclusively in terms of uniform circular rotations. The diagram to the right shows the solid spheres rotating in accordance with the uniformity condition geometrically represented on the left. (5, 6)*



Ptolemy's Planetary Hypotheses *exerted enormous influence on the development of Arabic astronomy. In it Ptolemy presented the motions of the planets in terms of solid spherical bodies corresponding to the geometrical representations in the* Almagest. *The impressive work of the Marāgha school in the VII/13th century and of Ibn ash-Shātir in the VIII/14th century would have been inconceivable without a strong commitment to the programme outlined in the* Planetary Hypotheses. *These diagrams from Part II of Ptolemy's book, of which the Greek original has not survived, illustrate Ptolemy's models for Saturn and the sun, respectively. (7)*

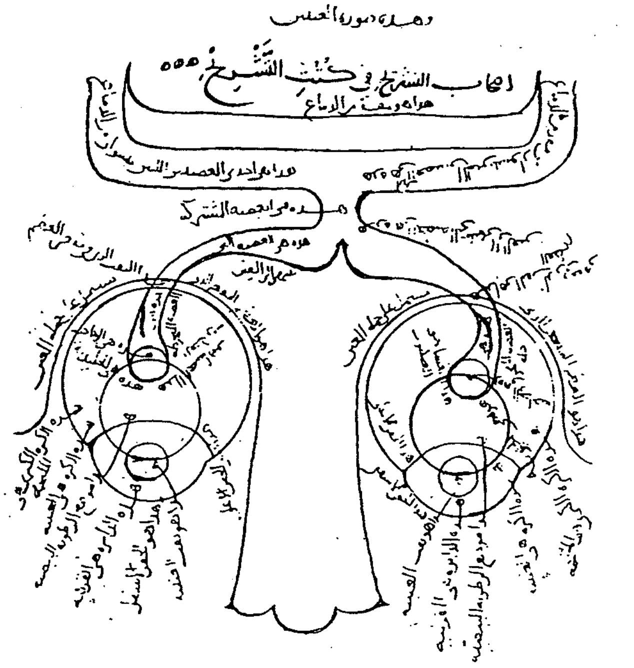
the Ptolemaic explanation of the apparent motions of the planets by means of epicycles and eccentric deferents on which the epicycles revolved. But he charged that Ptolemy's equant hypothesis, according to which the epicycle-centre appeared to move uniformly from a point other than the centre of the deferent or the centre of the world, violated the accepted principle of uniform velocity for all heavenly bodies. Ptolemy, and no doubt other astronomers, had been aware of what was entailed by the equant hypothesis. But while Ptolemy had tried to produce arguments in defence of his procedure, and in contradistinction to the astronomers who, as far as we know, had preferred to be silent on the matter, Ibn al-Haytham insisted that Ptolemy's constructions must be declared false and that new constructions must be found. His criticisms, and those of at-Tūsī and his collaborators at Marāgha, are an indication of the profound influence which Ptolemy's *Planetary Hypotheses* exerted on Islamic astronomers. In this work Ptolemy had conceived of the apparent motions of the planets as produced by the combined motions of corporeal spherical shells in which the planets were embedded. It was the idea that a physical body, the deferent sphere associated with a given planet, should rotate with variable speed, that Ibn al-Haytham and those who shared his views found unacceptable. Unwilling to abandon the physicalist view, the astronomers at Marāgha set out to construct models which would be mathematically equivalent to those of Ptolemy but which would also be in accord with the nature of the heavens. Only such models could possibly be considered true. Observations play no essential part in this story, either as causes or as consequences. The theoretical innovations developed at Marāgha and by Ibn ash-Shātir were imaginative and ingenious attempts to straighten up Ptolemy by bringing him into line with his own principles; but their authors show no desire to break away from his system.

Light and vision

Experiments of various kinds are described in medieval Arabic works on medicine, alchemy, mechanics, specific gravity and music, among other subjects. A certain taste for experimentation has been noted in the writings of so-called theologians or *mutakallimūn*, such as an-Nazzām (d. *c.* 226/840). It was in the field of optics, however, that a concept of experiment clearly emerged as an identifiable method of procedure in empirical enquiry. The sources of Arabic optics were the writings of the mathematicians Euclid, Ptolemy, Archimedes and Anthemius, the medical treatises of Galen and the philosophical works of Aristotle and his commentators. At first, these three traditions remained separate. Al-Kindī in the III/9th century wrote in the manner of Euclid; Hunayn ibn Ishāq in the same century approached the problem of vision from a Galenic point of view; and Avicenna in the V/11th century treated the subject in Aristotelian terms.

Ancient and medieval optics was primarily a theory of vision. In Islam, mathematicians and the followers of Galen held the view that vision occurred through a ray which issued from the eye towards the object, and either by touching the object or compressing the intermediate air conveyed an impression of the object to the brain. Natural philosophers spoke of vision as resulting from the impinging of a 'form' of the object on the eye. The most important student of optics in Islam, Ibn al-Haytham, was convinced that a correct theory of vision must combine the 'mathematical' approach of Euclid and Ptolemy with the 'physical' doctrine favoured by the natural philosophers. The result of his deliberations in his major work on *Optics* was a new theory of vision which was richer and more sophisticated than all preceding theories. He considered that light and colour, two physical properties which existed independently of the perceiving subject and of each other, emanate from every point on the visible object rectilinearly in every direction. With the help of suitable assumptions (some of which concern the geometrical structure of the eye), he set out to show how an entity (called by the Aristotelian name of 'form') capable of representing the visible features of the object first occurs in the eyes, whence it is carried to the brain, where it is apprehended by the faculty of sense. This entity is not an image which can be seen anywhere inside the eye, though it is the means by which a picture of the object is ultimately worked out and made to appear to the sense faculty. The apparently immediate judgment that what is perceived is an object which lies at a distance from the eyes, and which has, for example, a certain size and shape, is, according to Ibn al-Haytham, the result of an 'inference' from the visual material received in the brain and the stored information of past experience. Ibn al-Haytham did not only champion the intromission hypothesis, nor did he merely subject it to mathematical treatment; he incorporated that hypothesis into a highly elaborate theory of perception which has yet to receive sufficient attention from historians.

Arguing for the basic view that vision resulted from an effect of light upon sight, Ibn al-Haytham cited certain experiences such as those of after-images and the pain felt in the eyes when gazing on a strong light. These observations were not in themselves new, but in the *Optics* they illustrate an experimental approach which



Ibn al-Haytham's Optics, *written in Egypt in the first half of the V|11th century, represented a theory of vision that went beyond Galen, Euclid and Ptolemy. This diagram of the two eyes seen from above, showing the principal tunics and humours and the optic nerves connecting the eyeballs to the brain, is from a copy of the First Book executed by the author's son-in-law in 476|1083, i.e. about forty-three years after Ibn al-Haytham's death. Though we may assume that the copyist was probably transcribing an autograph manuscript, the diagram does not adequately represent the geometrical arrangement of the various parts of the eyes, which is meticulously described in Ibn al-Haytham's text. The diagram below is a later and more accurate illustration of the same text; it comes from a 14th-century Latin version of the* Optics, *which had first been translated a century or two earlier. (8, 9)*

characterizes the whole book. The concept of testing, already found in astronomy, here explicitly appears as a distinct concept of experimental proof, and it is by manipulative experiments that Ibn al-Haytham seeks to establish such properties of light as rectilinear propagation, reflection and refraction. 'Dark chambers' are some of the devices used in these experimental studies.

The Arabic equivalent of the expression *camera obscura* occurs in a chapter of the *Optics* which is missing from known manuscripts of the medieval Latin translation of this book. The expression may have been originally derived from Greek works. But though dark chambers are utilized in the *Optics*, no proper *camera obscura* images are described anywhere in it. This is interesting, because it means that the eye is not considered in this book as a pinhole camera (nor, of course, is it assigned the role of a lens camera).

That Ibn al-Haytham had some, rather advanced, knowledge of the working of the *camera* is, however, clearly revealed elsewhere in his writings. In a treatise on *The Shape of the Eclipse*, he made an attempt to explain the crescent image cast by the partially eclipsed sun through a small round aperture. His experimental study of this phenomenon, which had been of interest to astronomers for many centuries, makes use of two principles. The first stated that light from all points on the shining crescent simultaneously passed through every point in the circular hole, thus producing infinitely many inverted crescent images on the screen behind the hole. The second principle stated that light emanating from each individual point on the crescent sun in the shape of a cone determined by the size and distance of the hole, produced a

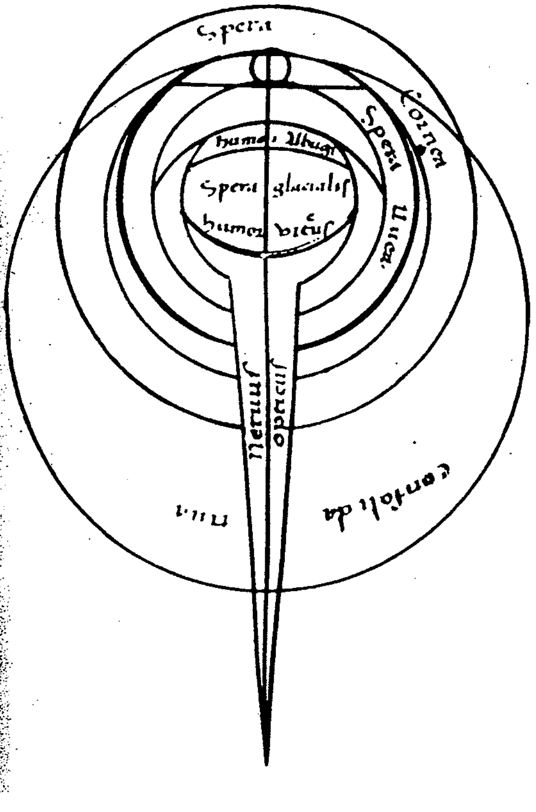
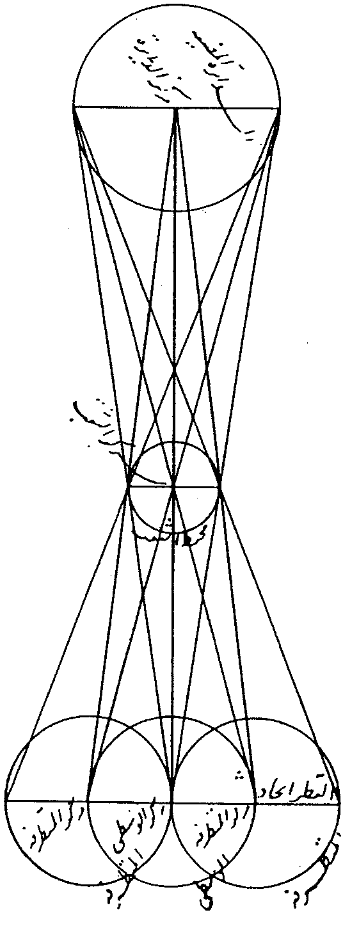


Diagram illustrating two principles of the camera obscura *from a résumé of optics by Kamāl ad-Dīn al-Fārisī (early VIII|14th century). These principles had already been applied three hundred years earlier by Ibn al-Haytham in his explanation of the formation of inverted images through a small circular aperture. The circle at the top is the light source, that in the middle is the aperture. The light emanating from individual points on the circle passes through the hole in the form of a cone. The three intersecting circles at the bottom are the images cast by three such cones. Light from the circle as a whole, on the other hand, converges at the centre of the aperture and diverges on the other side, producing the middle circular image, which is inverted. (10)*



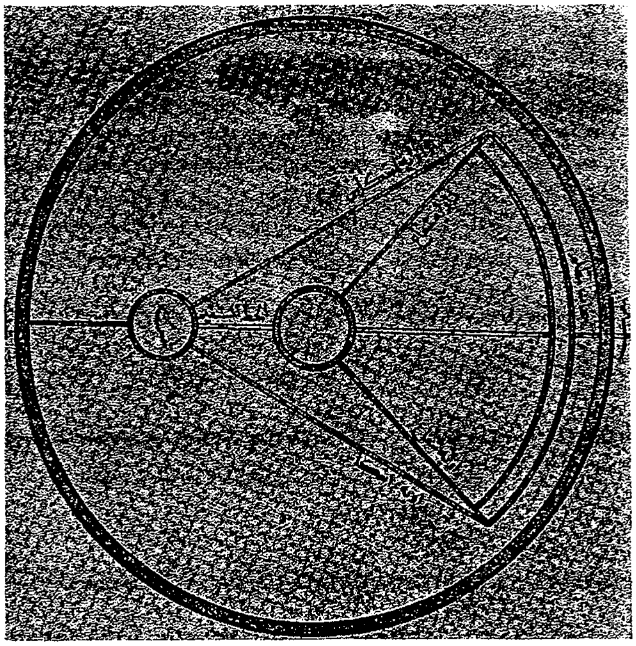


Illustration of Avicenna's (Ibn Sīnā's) explanation of the rainbow. From a late X/16th-century copy of a Turkish version of al-Qazwīnī's popular cosmography Wonders of Creation. *The light from the rising sun (small circle on left) is reflected to the observer from two points on a 'dark cloud' (double arc on right). Avicenna (wrongly) emphasized that a dark background was necessary for the raindrops to act as mirrors. (11)*

circular image on the screen. Ibn al-Haytham considered that the observed image was the combined effect of the images produced in accordance with these two principles. As far as we know, the treatise containing these results was not known to medieval Latin authors.

The rainbow was another phenomenon whose experimental study in Islam was remarkably successful. With regard to this phenomenon, Avicenna declared himself 'unconvinced by what our friends the peripatetics said about it', and he even went as far as to assert that current explanations of the rainbow colours were 'all false and absurd'. In the section of his *ash-Shifā'* dealing with meteorology, he related his own 'repeatedly made' observations of the bow, but failed to produce a satisfactory explanation, admitting that as far as he was concerned the rainbow remained a puzzling phenomenon. He did, however, emphasize the role of water droplets in generating the bow – an idea which had appeared in Aristotle and which was to inspire the Persian Kamāl ad-Dīn more than two hundred and fifty years after Avicenna's death.

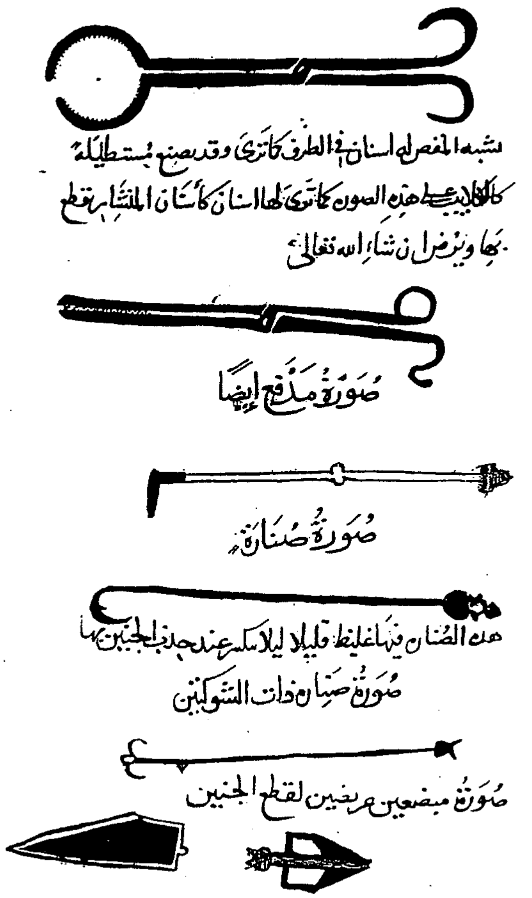
Kamāl ad-Dīn, who made a careful study of Ibn al-Haytham's *Optics*, started his investigations from the rules of refraction experimentally determined by his predecessor, and from the latter's study of the behaviour of light as the parallel rays from the sun passed through a burning sphere. The raindrop and the glass sphere had already been mentioned by Avicenna in the same context, and it remained for Kamāl ad-Dīn to explore the analogy between them by means of the geometrical tools at his disposal. The research on which he thus embarked is a remarkable example of experimental science which was only surpassed in modern times. By bringing mathematics to bear on the experimental situation in which a spherical glass vial filled with water stood for the raindrop in the moist air, he was led to the successful explanation which had defeated all his predecessors since Aristotle. The primary bow, he showed, was produced by the light of the sun that reached the observer after two refractions and one reflection inside the raindrops hanging in the atmosphere. He also showed that the secondary bow was produced by the light that had been reflected twice inside the raindrops, in addition to being refracted upon entering and leaving the drops, before reaching the observer. His explanations accounted for the shape of the rainbow and for the fact that the order of the colours in the secondary bow is the reverse of their order in the primary bow.

The history of experimental science in Islam, as exhibited in optical research, presents us with a few short-lived outbursts of creative activity, separated by long intervals of gestation or stagnation. A period of more than a hundred and fifty years separated the conservative treatises of al-Kindī and Hunayn from the revolutionary work of Ibn al-Haytham. And Ibn al-Haytham's *Optics*, written in Egypt in the first half of the V/11th century, appears to have remained practically unknown to scholars in the Islamic world until Kamāl ad-Dīn applied himself to its study in Persia at the end of the VII/13th century. Already in the same century, however, a Latin translation of Ibn al-Haytham's book had become the subject of intensive study in the West, where it was recognized as the most important source of optical knowledge.

Al-Andalus versus the East

The first notable philosopher in the Muslim East, Ya'qūb ibn Ishāq al-Kindī, died *c.* 257/870. The beginnings of serious interest in philosophical thought in Muslim Spain have been connected with the name of Muhammad ibn Masarra, a Neo-platonizing thinker from Cordoba who died in 319/931. The distance between their dates may be taken as an indication of how far al-Andalus lagged behind the East in the cultivation of the ancient sciences. But this would only be a rough indication. Ibn Masarra is a vague and confused figure compared to that of al-Kindī, and with his interest in Sūfism and the ascetic life it is even doubtful whether he can be called a philosopher in the sense in which this term would apply to al-Kindī. It was not in fact until the V/11th and VI/12th centuries that Muslim Spain produced really forceful figures in the field of science and philosophy, though elements of ancient learning had begun to arrive in al-Andalus from the East in the III/9th and IV/10th centuries, if not earlier.

The vicissitudes of intellectual life in Muslim Spain show certain parallels with earlier developments in the East. The role of al-Ma'mūn as an enthusiastic patron of the scientific activity at Baghdad is paralleled by the role of al-Hakam II a century later at Cordoba. Already as crown prince under the reign of his father 'Abd ar-Rahmān III (300–50/912–61), and until his death in 366/976, al-Hakam showed real interest in promoting the cause of science and philosophy in his country. He sent emissaries to Egypt and Iraq, among other Muslim countries, in search of books, and gradually built up at Cordoba a library which was said to have almost equalled the great 'Abbāsid collections. He employed copyists to duplicate rare manuscripts and generally encouraged scholars in the secular branches of learning. Thus the



Probably the first encyclopaedic work of medical instruction and practice to have been written in Muslim Spain was the Kitāb at-Tasrīf *of Abū 'l Qāsim az-Zahrāwī, the Abulcasis of the Latins, native of Madīnat az-Zahrā' near Cordoba, who died about 404/1013. The* Tasrīf *consists of thirty treatises, of which the last was devoted to the art of surgery. In some manuscripts this treatise displays more than two hundred drawings of surgical instruments designed and originally drawn by the author. The drawing reproduced here illustrates various types of scrapers, scalpels, hooks and forceps, some of which were to be used in obstetric operations. Translated into Latin by Gerard of Cremona in the 12th century, this surgical treatise received more attention in the West than any other part of az-Zahrāwī's book. (12)*

ancient sciences received their first powerful impetus in Spain from the royal court, just as had happened earlier at the beginning of the ʿAbbāsid era.

It was in the reign of ʿAbd ar-Rahmān III, shortly after the year 341/952, that a new Arabic translation of Dioscorides' *Materia medica* was undertaken at Cordoba. The translation was based on an illustrated Greek text received shortly before as a gift from the Byzantine Emperor. A monk from Constantinople who read Greek, Christians knowing Latin, and Arabic scholars collaborated in this work with the help of the Jewish scholar Hasdāy ibn Shaprūt, who was physician to ʿAbd ar-Rahmān. Until this translation was made Dioscorides' fundamental work had been known both in al-Andalus and in the East in a version prepared at Baghdad in the III/9th century by Stephanus, son of Basilius, and revised by Hunayn ibn Ishāq. Many of the Greek names of drugs in the Stephanus–Hunayn version had been simply transliterated, and it was the task of the new translators to identify the corresponding Arabic names with the help of the illustrations contained in the Greek manuscript.

A reaction set in after the death of al-Hakam, comparable to the religious reaction which had taken place under the ʿAbbāsid Caliph al-Mutawakkil (233–47/847–61). At the instigation of the powerful *ʿulamā'*, books on the rational sciences in al-Hakam's library (excluding those on arithmetic and medicine) were burned, drowned or buried, and the philosophic and scientific movement went underground. After the end of the Umayyad rule in 422/1031, however, a revival took place as a result of the ensuing competition between the petty states which sprang up all over al-Andalus. This again paralleled the efflorescence of learning in the East after the ʿAbbāsid empire broke up towards the middle of the IV/10th century into independent states which vied with one another for cultural prestige as well as political power.

With only a few exceptions, e.g. the astronomer az-Zarqālī, who flourished around 463/1070, the important figures in the history of science and philosophy in Muslim Spain all belonged to the VI/12th century. Not surprisingly, some of them knew and influenced one another. Ibn Tufayl, the author of the famous philosophical romance of *Hayy ibn Yaqzān*, was a court physician of the Almohad ruler Abū Yaʿqūb (559–80/1163–84), to whom he introduced the young Averroes. It was on the ruler's advice that Ibn Tufayl urged Averroes to write the commentaries on the works of Aristotle which later earned their author the title of 'The Commentator' in the Latin West. In 565/1169 Averroes was appointed judge of Seville; in 567/1171 he became chief judge at Cordoba; and in 578/1182 he replaced Ibn Tufayl as court physician. He continued to serve the Almohads until he fell into disgrace only four years before he died in 595/1198 during the reign of Abū Yaʿqūb's successor, Abū Yūsuf (580–96/1184–99). Averroes was a friend of the physician Abū Marwān ibn Zuhr, with whom he published a comprehensive medical encyclopaedia consisting of the *Kulliyyāt* (composed by Averroes) and the *Taysīr* (by Ibn Zuhr). The astronomer al-Bitrūjī was a younger associate of Ibn Tufayl; and from the latter he derived the idea of designing a non-Ptolemaic astronomical system more in agreement with Aristotelian principles. The need for such a system was also urgently expressed by Averroes in his large commentary on Aristotle's *Metaphysics*. Maimonides, a product of the same philosophical milieu, though he left Spain relatively young and eventually settled in Cairo, shared this negative attitude towards Ptolemaic astronomy. We seem entitled to talk about a philosophical and scientific movement.

This movement has been viewed as a revival of Aristotelianism initiated by the Andalusian philosopher Ibn Bājja, or Avempace (d. 430/1138), who is said to have fallen under the influence of the Second Teacher, al-Fārābī.

Spanish Aristotelianism exhibits, however, certain peculiar features which, it seems, can best be understood against the background of a growing Spanish attitude of self-assertion towards the Muslim East and its intellectual authorities. In the V/11th century this attitude became crystallized in the thought of Ibn Hazm of Cordoba, one of the most original minds in Andalusian history. Ibn Hazm developed the literalist (*zāhirī*) approach to Islamic law into a whole philosophy of religion. His aim was twofold: to protect the divine law from human encroachment; and, simultaneously, to define the domain of valid rational thought. The whole of religion, he argued, was explicitly stated in the Qur'ān and in the *ḥadīth*, and he accordingly rejected all forms of inference from these two sources. No human being, he said, had the right to propose the results of his own efforts, no matter what they were and no matter on what basis, in the name of religion. The religious commandments should be obeyed, he declared, not because they were derivable from reasons which could be discovered by human endeavour, but because they issued from divine authority. The Law was grounded in the divine will, not in human wisdom.

Ibn Ḥazm's view clearly implied a rejection of the authority of all the legal schools which had been founded in the East. His position was paralleled in a remarkable way by the later developments of thought in Muslim Spain both in the field of religion and in the secular sciences. The founder of the Almohad movement, Ibn Tūmart (d. 421/1130), apparently inspired by Ibn Hazm's literalism, accepted the Qur'ān, the *ḥadīth* and the consensus of the Prophet's Companions as the only sources of law; and he preached against accepting the authority of the Eastern masters of the established schools. The third Almohad ruler, Abū Yūsuf Yaʿqūb (580–96/1184–99), who, like Ibn Tūmart, was opposed to the proliferating systems of positive law elaborated by members of the various schools, urged jurists not to imitate the ancient masters and to base their judgments on the Qur'ān and the *ḥadīth*. Not only the masters of the legal schools but also the authorities of Arabic grammar came under fire from the literalist-inspired camp. Ibn Maḍā' of Cordoba, who achieved the position of chief judge under the Almohads (he died in 592/1196), wrote a refutation of the theory of 'the agent' which had been at the basis of Arabic grammar since Sībawayh (d. *c.* 179/795). He strongly repudiated the effort to look for grammatical 'causes' (corresponding to the 'reasons' of the legal theory), the only real cause of linguistic phenomena being, in his view, the *individual* speaker, not any hidden 'agent' which it was the task of the expert grammarian to uncover.

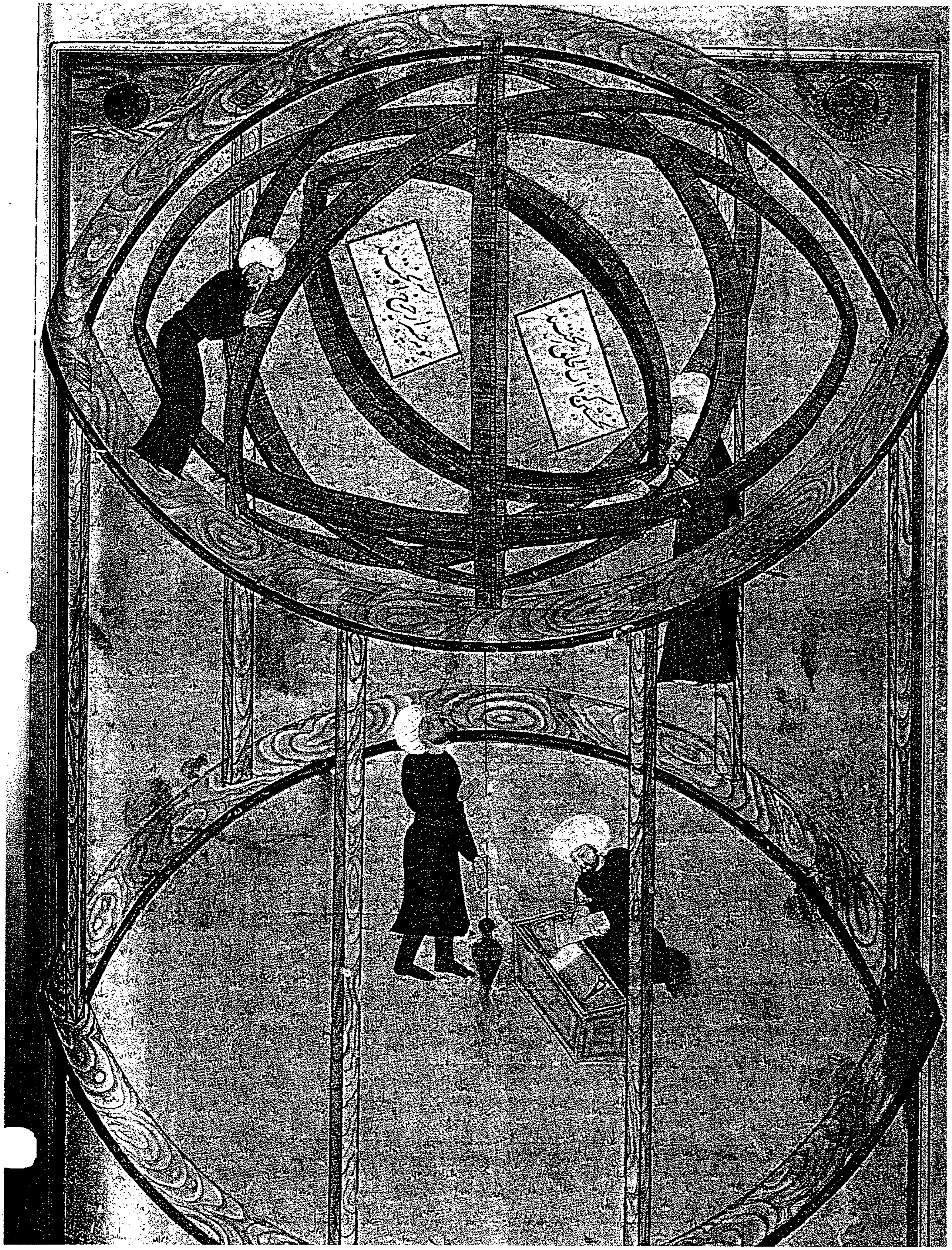
It is difficult not to see a parallelism between the literalist trend in Andalusian thought, with its aggressive overtones, and some of the characteristic philosophical and scientific ideas developed in the vi/12th centu under the Almohads.

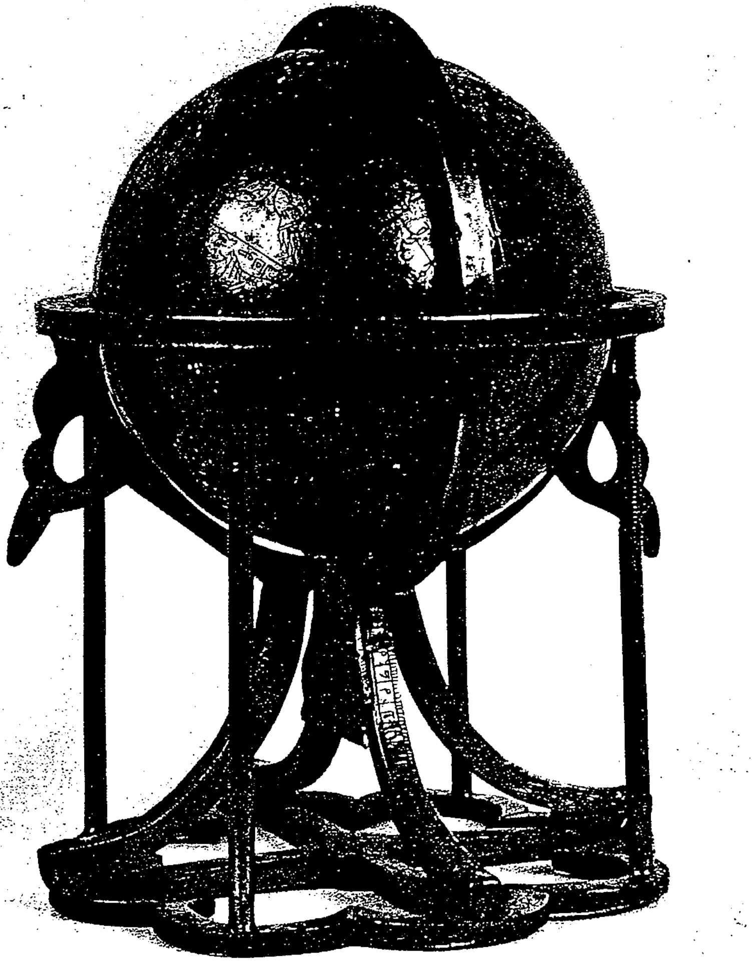
Averroes' 'pure' Aristotelianism, for example, was kind of literalism in philosophy which implied conden nation of the earlier Muslim interpreters (or corrupter of Aristotle. His *Incoherence of the Incoherence* was not on an attack on al-Ghazālī's *Incoherence of Philosophy*, but al a repudiation of pretended Aristotelians such as Avicen and al-Fārābī: one of al-Ghazālī's errors, according Averroes, was to attribute to the ancients doctrin which were in fact manufactured by Islamic peripatetic

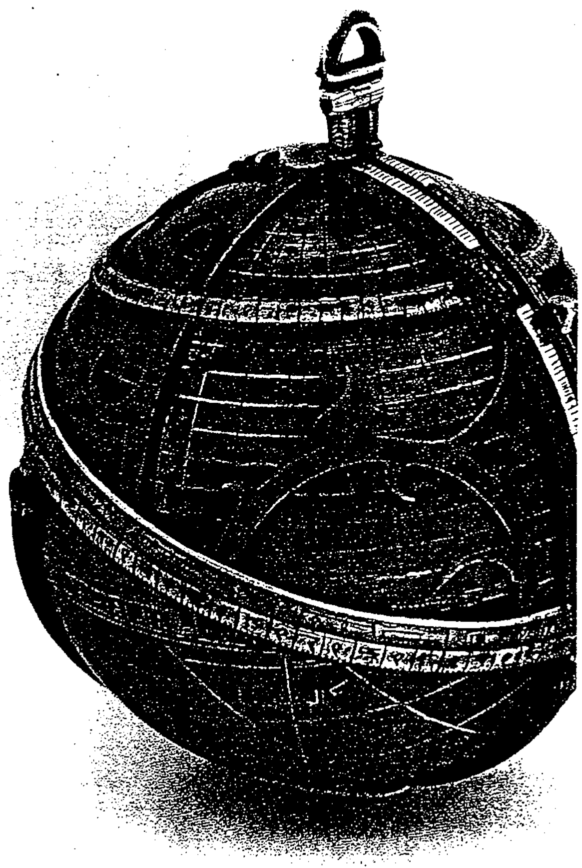
There is evidence to show that a connection exist between Averroes' nationalism and his vision of himse as the true heir to genuine Aristotelian thought. In h middle 'Commentary' on Aristotle's *Meteorology* he like the climate of al-Andalus to that of Greece (Cordoba not too far from the latitude of Athens), and draws t consequence that, like the Greeks, the inhabitants of h country were better disposed for philosophical thoug than, for example, the people of Iraq.

Averroes' attitude towards Ptolemaic astronon (which he shared with Ibn Tufayl and al-Biṭrūjī), is direct consequence of his view of Aristotle as the be and last philosophical authority. Thus whereas Avicen had included a summary of Ptolemy's *Almagest* in h *summa* of peripatetic philosophy, Averroes conclud from an examination of the Ptolemaic system in the lig of Aristotelian cosmology that 'the astronomy of o time agrees with computations, but not with what exist Averroes, like Maimonides, was thus aware of t strength of the Ptolemaic system of astronomy: it save the celestial phenomena. But the system made use eccentric and epicyclic spheres and thereby violated t Aristotelian conception of the world according to whic all celestial bodies must rotate about the unique centre the world. Since the Aristotelian theory was demo strably true, Ptolemy's system must be false. Averro was not himself able to discover an alternative syste but he urged others to continue the search. The theo proposed towards the end of the vi/12th century al-Biṭrūjī was a failure from the astronomical point view, but it stands as a witness to a unique situation in t history of Islamic science.

Islamic scientists always regarded their Greek mentors with profound respect, often with awe. But the best among them were not slavish followers of their Greek predecessors: they regarded such authorities as Galen and Ptolemy as fallible human beings who made mistakes and who ought to be criticized and corrected. In astronomy, Islamic mathematicians compiled a vast mass of observations, checking Greek and Persian sources and refining Ptolemaic parameters. They devised ingenious methods of computation, and posed and solved numerous problems in spherical trigonometry. They produced non-Ptolemaic models for the planets which have been compared to those of Copernicus, but made no attempt to abandon the Ptolemaic geocentric system of the world. In spite of substantial advances in optics, there were no telescopes, and research was confined to pinpointing t position and movements of heavenly bodies with t naked eye, as indeed was the case with all astronomy up Galileo. This illustration is from an Ottoman manuscri of the second half of the x/16th century, the *Shahinsha nāma*. The instrument is a giant armillary sphere, su ported by a wooden frame set up on the groun apparently in the open air. The five graduated rin correspond to five fundamental circles of the heaven The man in the centre is adjusting the meridian ring (th large circle seen in the foreshortening) with a plumblin Above him three astronomers are taking observation The two on the right seem to be looking along th graduated circles at some planet or star, while a assistant records the results. (1)



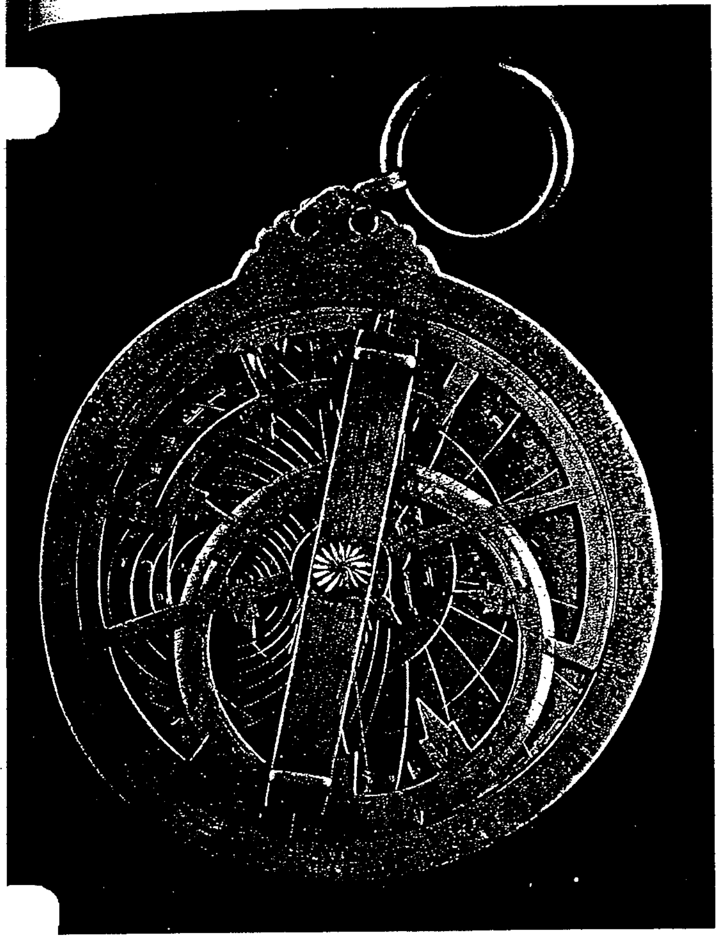




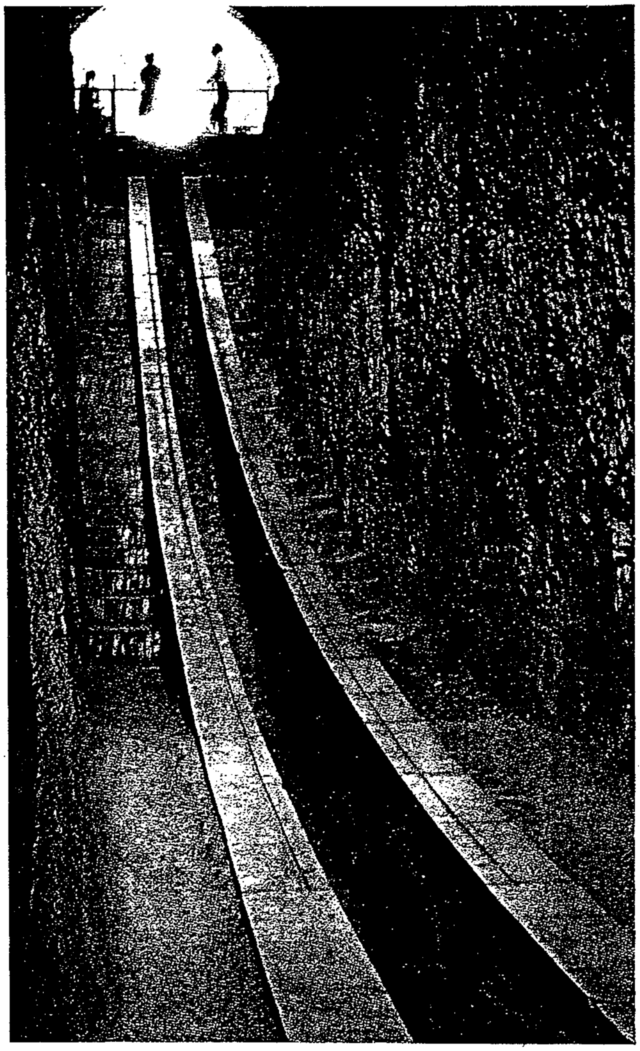
A celestial sphere from Iran is dated 684/1285. It incorporates information derived from ʿAbd ar-Rahmān as-Sūfī's *Book of Fixed Stars* (see opposite below). Stars are marked by points of silver. (2)

Spherical astrolabes were rare: this is the only one known to exist, dated 885/1480. The large ecliptic circle bears the names of the signs of the Zodiac. The *rete*, or star map, is attached to the globe with pointers for nineteen fixed stars. (3)

An observatory and centre for astronomical studies w founded at Marāgha in Azerbaijan by the Il-Khānid rul Hülegü about 657/1259. In charge was the great scient Nasīr ad-Dīn at-Tūsī, who is depicted with his collabc ators (below) in a x/16th-century manuscript. It was he that the tables known as the *Il-Khānid zīj* were drawn u incorporating the results of new observations. A pa giving the ascensions of the signs of the Zodiac f latitude 38° N is reproduced below. (4, 5)

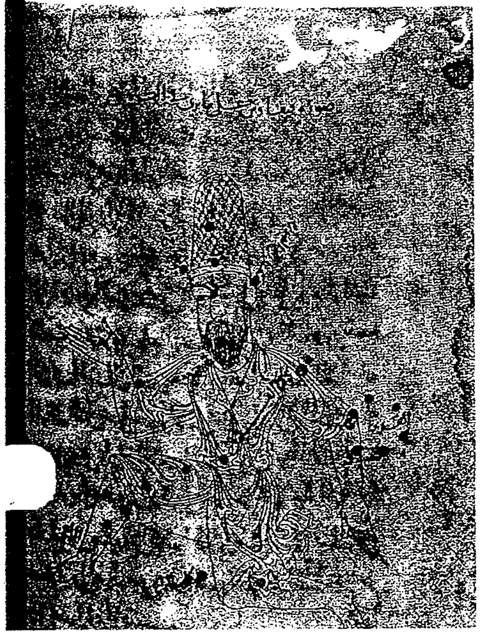


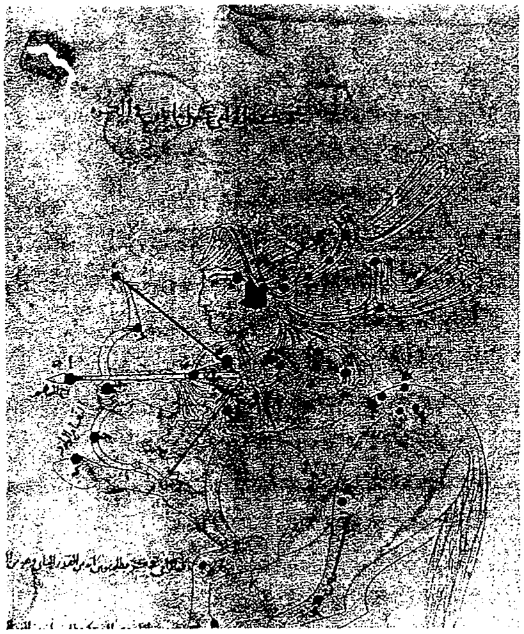
The astrolabe was for measuring the altitude of heavenly bodies above the horizon, and so determining (among other things) the time of day or night. Readings are taken by means of a rotatable alidade, a diametrical rule with sights. This example, the more normal planisphere, dates from the III/9th century. (6)

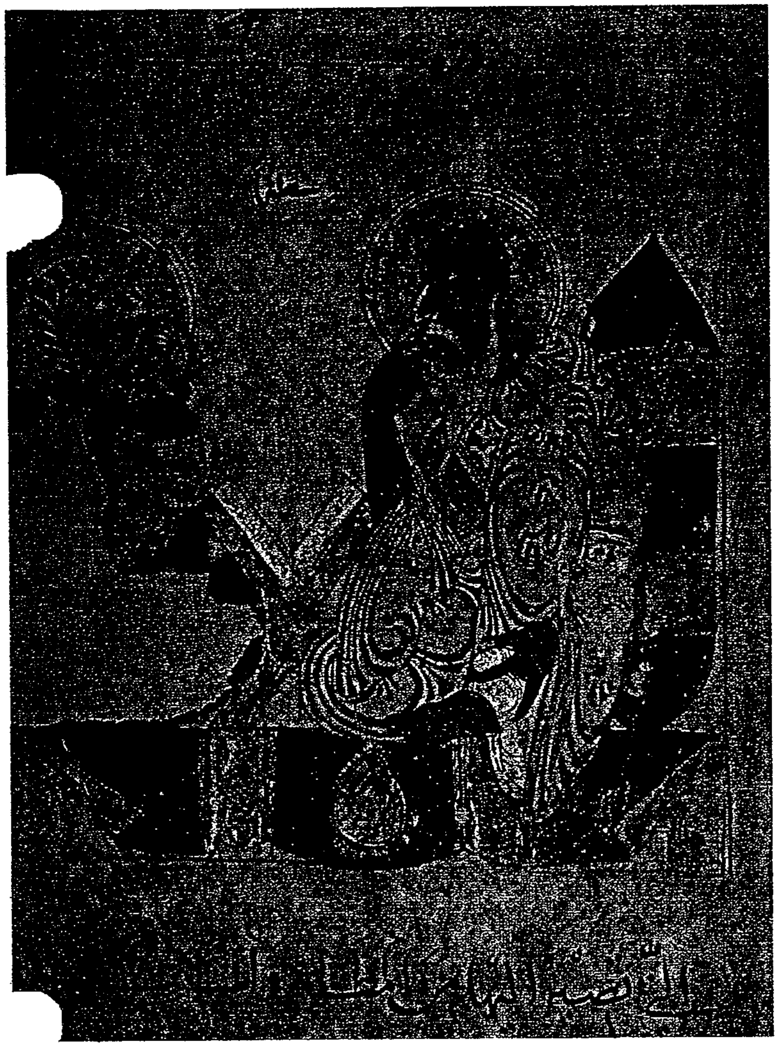


At Samarqand Sultan Ulugh Beg, the grandson of Tamerlane, founded another great observatory. This trough supported a large arc erected in the meridian plane. Celestial bodies crossing this plane cast light through an opening at the arc's centre onto a graduated cylindrical base, from which their altitudes could be read off. (7)

The Book of Fixed Stars was the main work of ʿAbd ar-Rahmān as-Sūfī (290–376/903–86). In it, following ancient Greek tradition, he represented the constellations by animal or human figures or by objects. Shown here are Cepheus, wearing a mitre; Sagittarius, represented as a centaur – both as in Ptolemy – and Andromeda, as seen on the celestial globe and in the sky. (8, 9, 10)





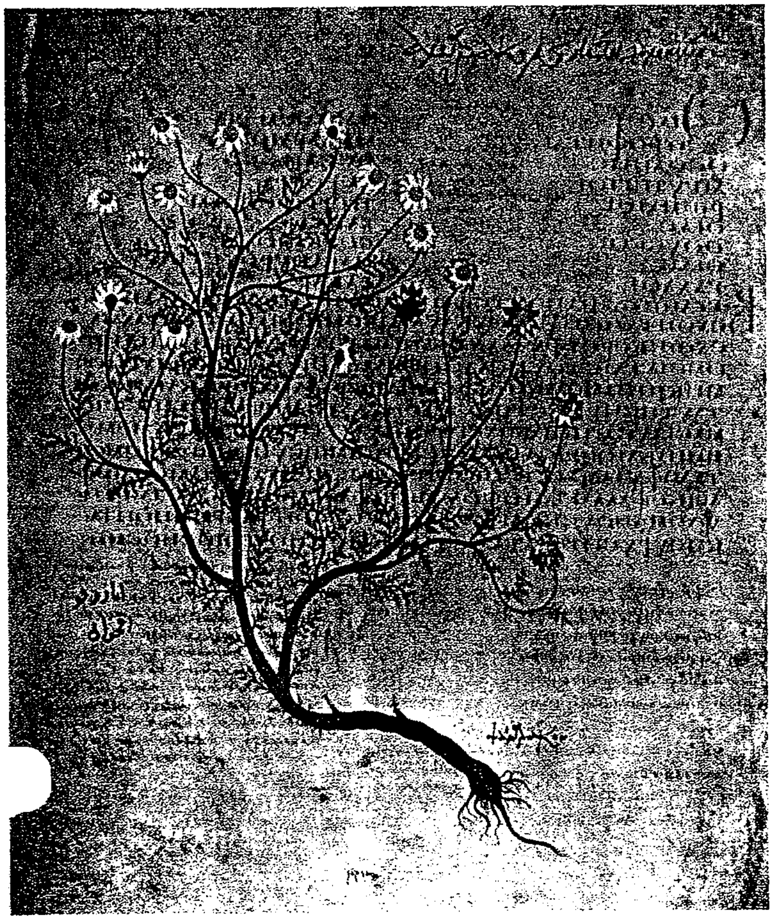


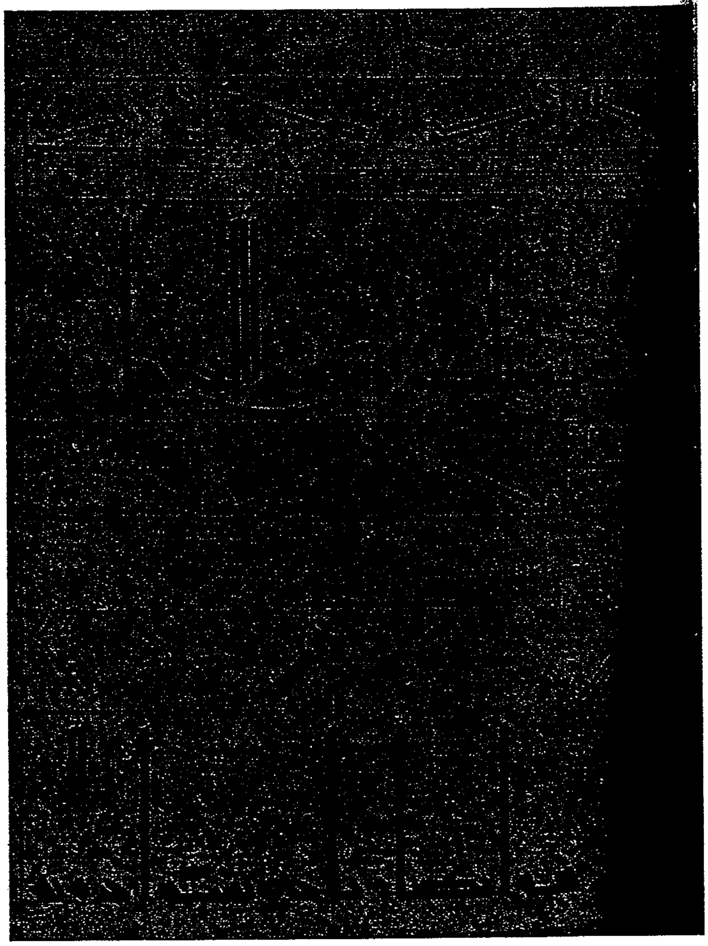
Aristotle was as seminal a figure in the East as in the West. A deliberate policy of translating his works was initiated by the caliphs as early as the II/8th century. He was known both as a philosopher and as a biologist. This portrait of him (left) comes from the *Description of Animals* by Ibn Bakhtīshū‘, early VII/13th century. (11)

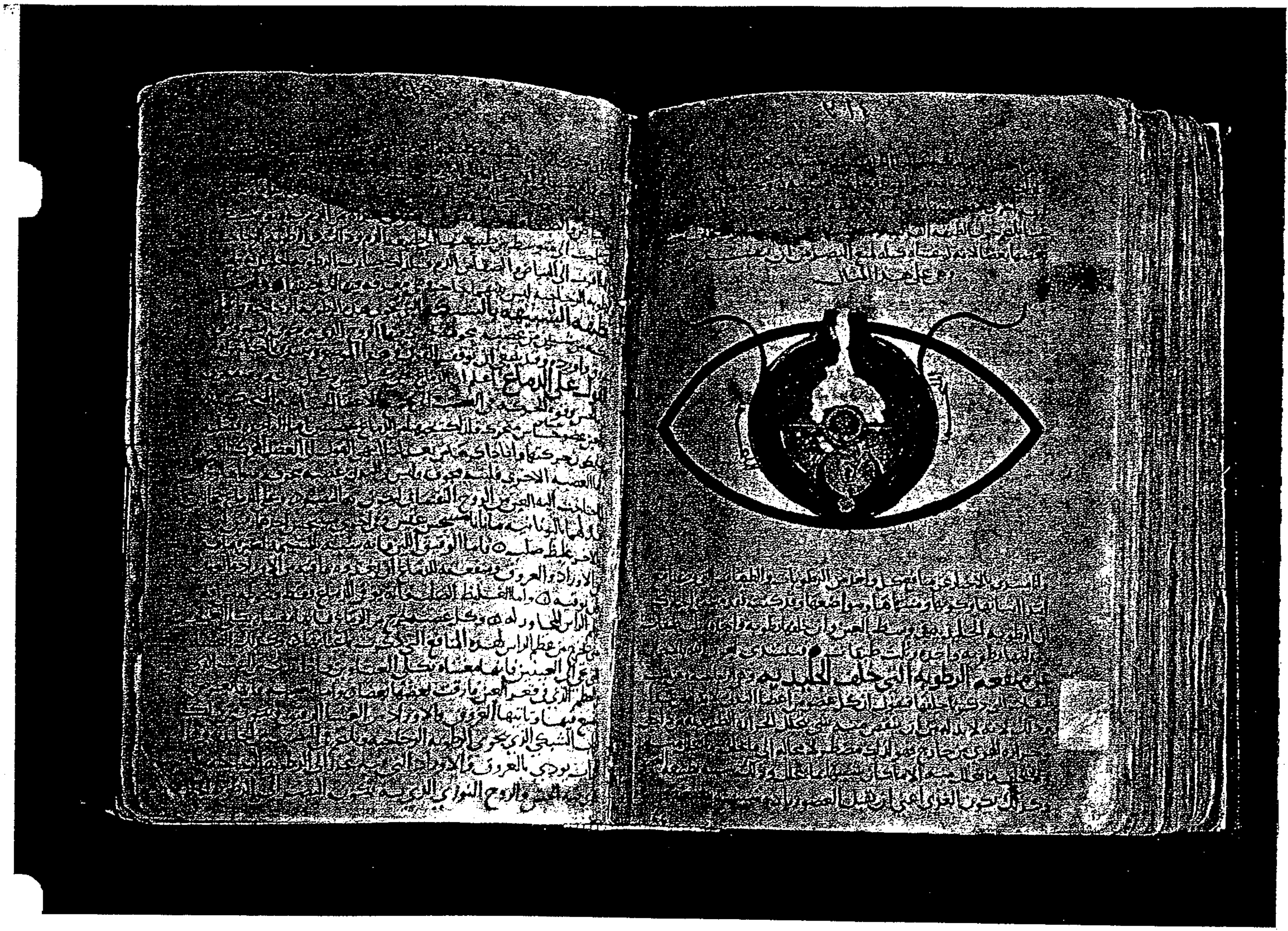
From Galen Islamic scientists inherited an empirical method of enquiry, a body of useful medical knowledge – and some errors. In optics Galen postulated a 'visual spirit'. Hunayn ibn Ishāq's *Book of the Ten Treatises on the Eye* (opposite) in the III/9th century adopted a Galenic theory of vision, but anatomically his work is outstandingly accurate. It was still a standard work in the VII/13th century, when this copy was made, although by that time a far more original treatment of the problem, Ibn al-Haytham's *Optics*, had been in existence for two hundred years. (14)

Dioscorides' treatise on herbs, one of the many Greek texts obtained from Constantinople in 512 (the Greek script shows through from the verso), is annotated with the name of each herb in Arabic. This one is saxifrage. (12)

The Book of Antidotes, attributed to Galen and John the Grammarian, was translated early and widely used in medicine. As on this page (below) the text is decoratively arranged, constituting one of the earliest of all Arabic illuminated manuscripts, 595/1199. (13)





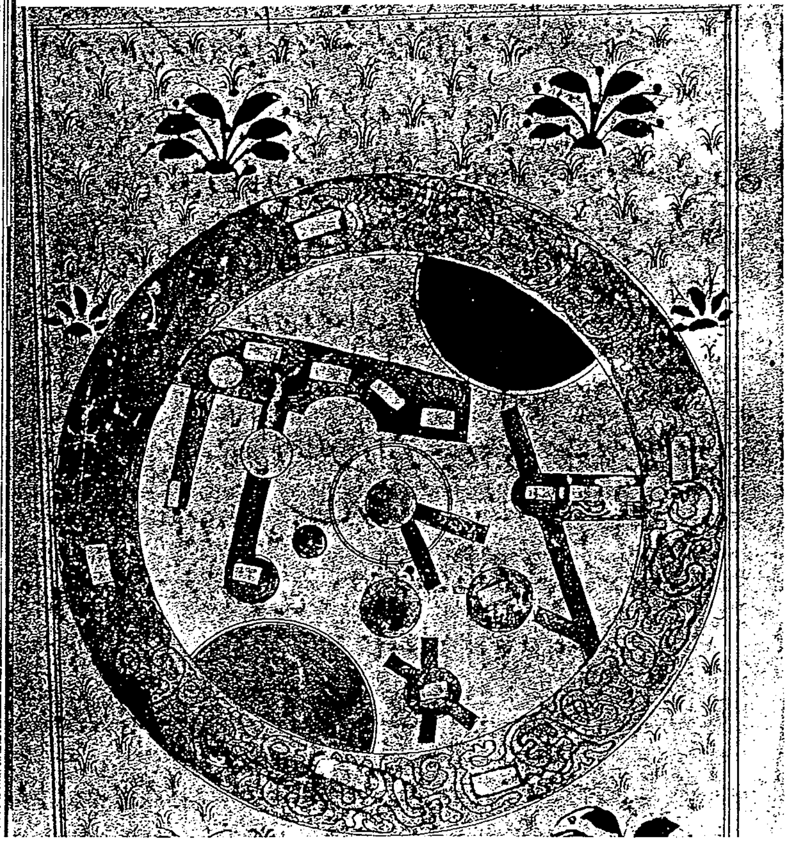


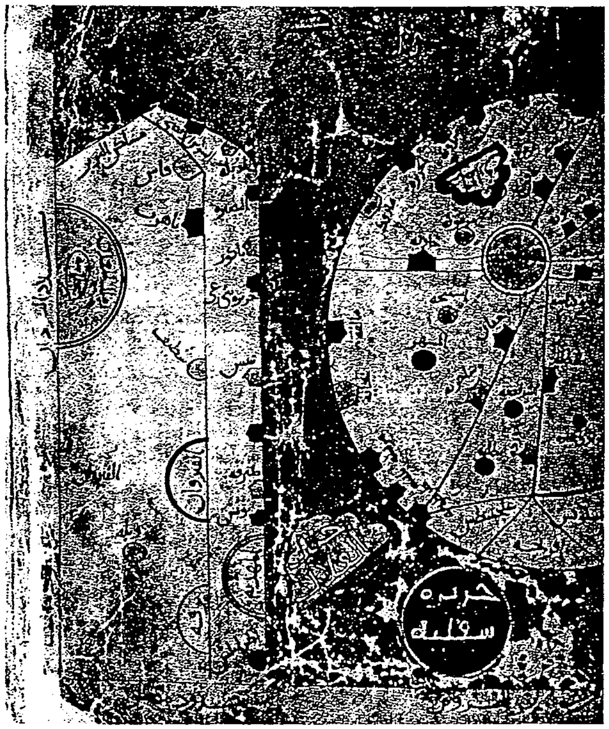
A pharmacist prepares his drugs. The scene comes from a VII/13th-century Arabic version of Dioscorides' *Materia Medica*, a work whose influence lasted until the 19th century. (15)

Arabic medicine was in advance of European throughout Middle Ages, and from the first medical school of rno down to Vesalius, Western doctors learned from their Muslim counterparts. This anatomical plate from a Persian *Medical Treasury* is as late as the XI/17th century. (16)

The world takes shape: Arab geographers understood the basic outlines of Asia, Europe and North Africa by the VI/12th century, and their knowledge was summed up in the great atlas of al-Idrīsī of 549/1154 (above). It places south at the top; we have inverted the map to make it recognizable. (17)

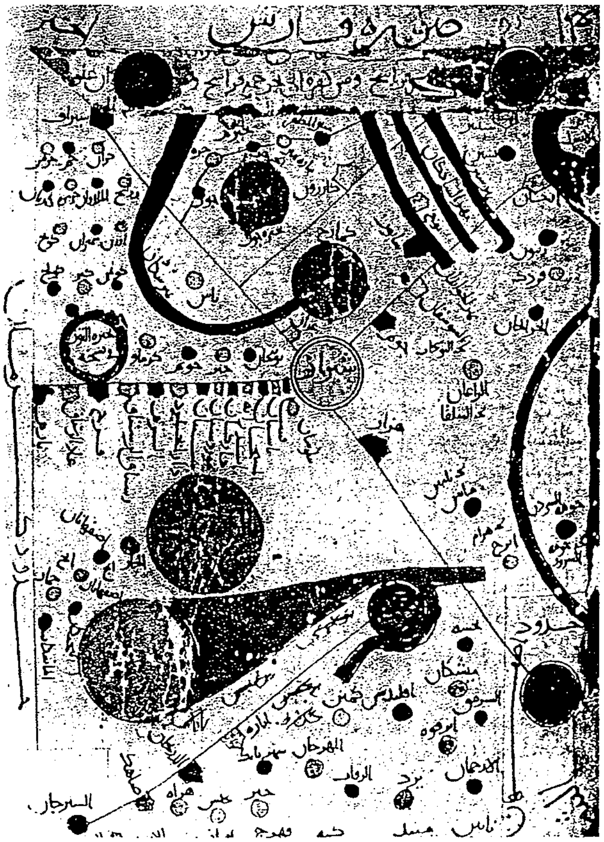
A schematic world, analogous to the Christian *mappamundi*, was common in Islamic atlases beginning in the III/9th century. A Baghdad example (791/1388) from al-Qazwīnī's *Wonders of Creation* is shown below. The world is surrounded by water, with the Mediterranean cutting into it from the west and the Red Sea from the east. (19)



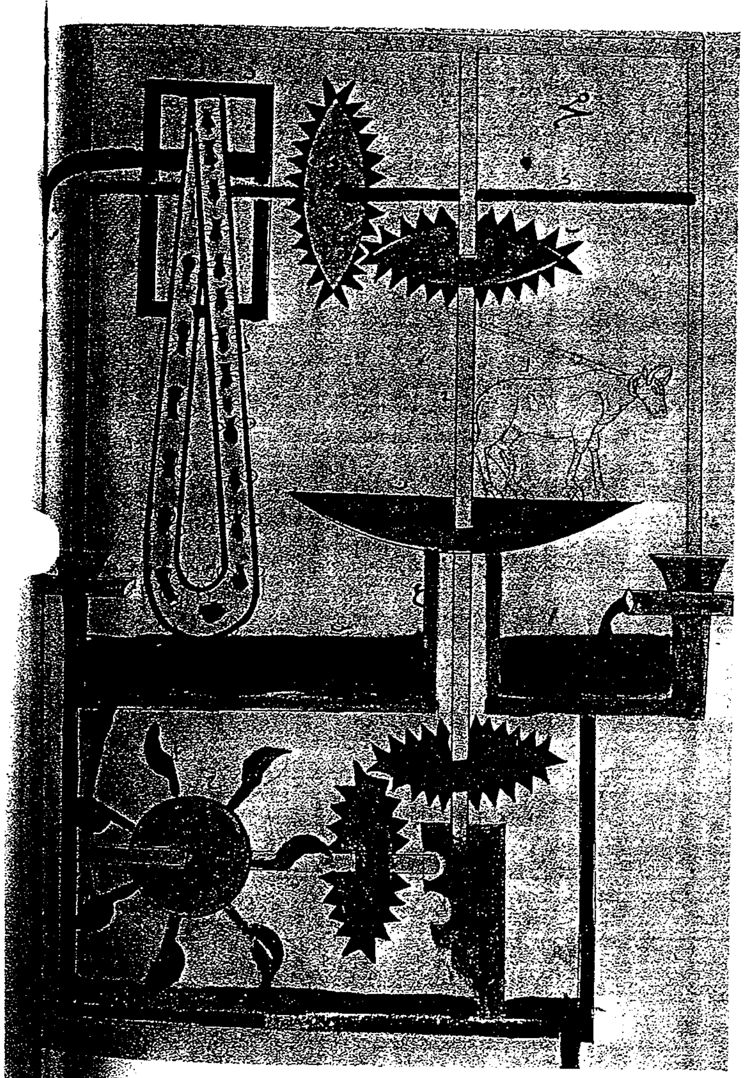


The Mediterranean is given a more schematized form
this IV/10th-century map from al-Istakhrī's *Book*
Countries. Spain is on the right; the circle near the midd
contains the name of Cordoba. The black circle at tl
bottom is Sicily. On the left, North Africa. (18)

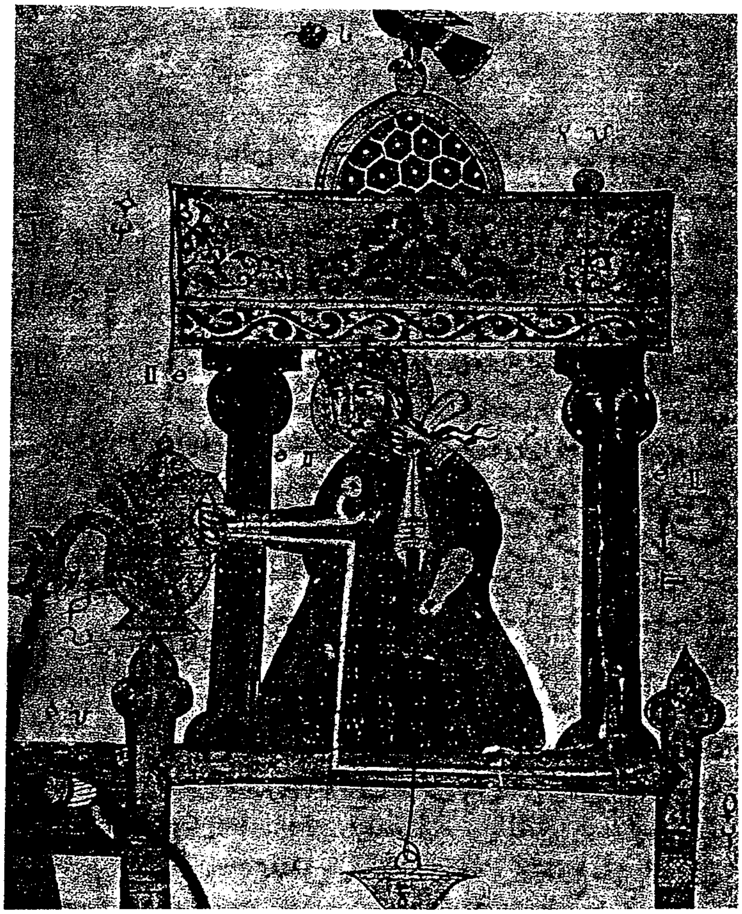
The country round Shīrāz in Iran is shown in this det
from al-Istakhrī's *Book of Countries.* South is top le
north bottom right. Shīrāz itself is marked by the doub
circle in the middle. Istakhrī's maps are really styliz
itineraries showing towns and the roads between thei
(20)



The toy-like forms of al-Jazarī's *Automata* should not distract attention from their mechanical ingenuity. His book was written about 603/1206; the illustrations on this page are from manuscripts of a century later. The device on the right is for measuring the amount of blood taken from a patient during blood-letting. The blood runs into the basin in the centre. As this gets heavier it operates a pulley which moves the two scribes sitting at the top. One points to a circle divided into 120 units (one for each dirham, i.e. about three ounces), the other to a tablet similarly divided. (22)



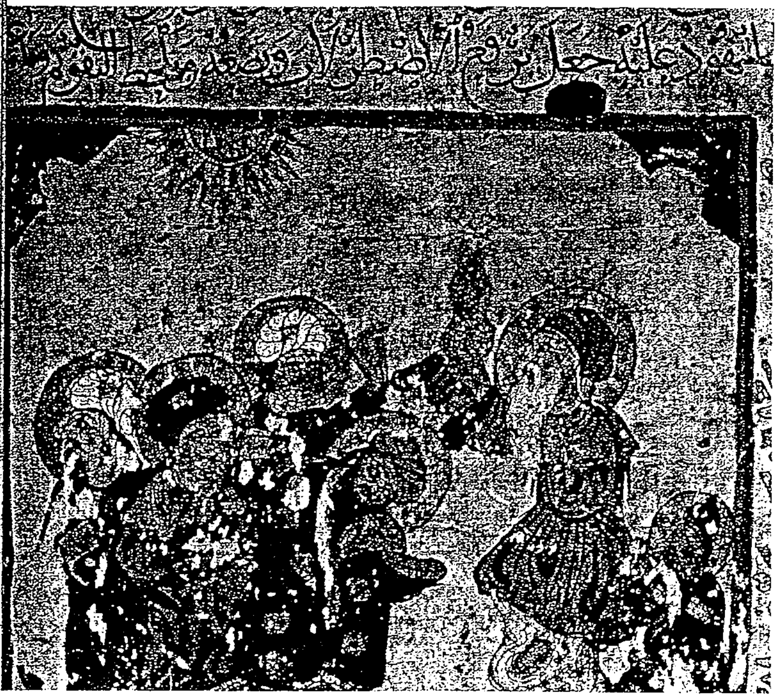
A hydraulic pump: the water flowing into the pool from the right discharges through a pipe in the bottom of the pool, thus causing the scoop wheel (bottom left) to turn. Through the enmeshed toothed wheels (beneath and above the pool) the motion is transferred to a wheel (top left) to which roped jars are attached. The jars scoop the water off the pool, and lift it to the top of the machine where it is discharged into a channel. Halfway up the long vertical shaft an ox revolves, as if providing the motive power. (21)



A mechanical wash-stand (right): water runs from the tank at the top, through the pitcher held by the servant, into a basin. The owner washes his hands and the water

The study of the heavens eagerly pursued in almost e Islamic country, partly – as Europe – because of its relev to astrology. Here astronomers working at the short-lived 16th-century observatory buil Istanbul by Murād III for ad-Dīn, the clock-maker tur astrologer. On the far side of large table in the middle of room an astronomer (Taqī Dīn?) holds an astrolabe; the to his right looks through an dade attached to a quadrant; w another, at the far left, l through a diopter. (24)

The indispensable instrument mained the astrolabe, almost ways planispherical and mad bronze or brass. Astronomers astrologers used it throughout Islamic world, and many trea were written on its construc and use. With it the altitude celestial bodies could be meas with the help of a rotating alid From such information the tim day or night could be determi As an analogue computer structed on the principles of ste graphic projection, it was used solving problems in sphe astronomy. Below left: scene an astrologer holding an astrol from a VII/13th-century *Maqā* Below: astrolabe made in Cair 634/1236, of engraved brass in with silver and copper. (25, 26)



Chapter Eight

ARMIES OF THE PROPHET

Edmund Bosworth

A mounted archer or fāris *of the Mamlūk army* c. *700/1300, from the so-called Baptistère de St Louis. Note the composite bow and bow-case, and the kite-shaped shield on the rider's back. Practice in shooting from horseback was one of the principal features of the* furūsiyya *exercises or trials of skill in the equestrian arts and in weapon handling. (1)*

One of the popular stereotypes which grew out of the long centuries of Muslim–Christian religious antipathy and warfare over possession of the Mediterranean basin was that of the bellicose and bloodthirsty Saracen, impelled by the fanaticism of his Faith and by a prospect of the Muslim paradise of houris and gardens, the prize of the warrior slain in *jihād*, or battle for the Faith. Certainly, the most spectacular and continuous contact between Islam and Christendom was on the military and naval planes. For some eight centuries, Constantinople lay as the supreme goal of Muslim arms, just as the recovery of the Christian Holy Places in Palestine and the patriarchal seats of Antioch and Alexandria did for the Latin Crusaders. Moreover, when, in regard to the Christian shrines, the Crusaders had resigned themselves to relinquishing their last footholds in the Levant, and when in regard to Constantinople, the Muslims achieved their aim in 857/1453, the sequel to these centuries of accumulated mistrust was a continued clashing by land and sea: the Ottoman Turkish imperial expansion into the Balkans, and the Spanish and Portuguese attacks on Muslim North Africa, although the purely religious motive gave place from the XI/17th century onwards to motives of political, economic and strategic domination. It must be admitted that there is some truth in the medieval and later stereotypes of the Muslim warrior-fanatic, the *ghāzī* or *mujāhid*; and memories of the religiously inspired desperadoes, the Assassins, in VI/12th- and VII/13th-century Syria and Persia have retained favourable enough connotation in the modern Islamic world for the Arabic term applied to such a desperado, *fidā'ī*, to be revived in the Persian and Arabic worlds and applied to religiously or politically motivated terrorists, the *fedayeen*: those eager to sacrifice their lives. A good proportion of the successive ruling dynasties of the caliphs and their epigoni in the provinces, and of the great empires in the later medieval period, such as those of the Mongols, the Mamlūks, the Ottomans, the Safavids and the Mughuls, certainly had their origins in military conquest or revolutionary movements, within some of which religious motives were interwoven; and the regime arising from a military coup continues to be the norm over much of the contemporary Arab world. The alarums of war often impinged on the daily lives of Muslim peoples. Lands were trampled over by invaders or by internal rebels and aspirants to power, and towns were sacked. As the medieval Islamic world evolved, much of its governmental apparatus, and especially its land tenure system, became geared to making war. It is for factors such as these, then, that the topic of warfare and military organization in Islam is worthy of isolation and study.

Within the cultural and social backwater that was Arabia, the basic military feature of tribal life was the *razzia* or raid (from Arabic *ghazw*, *ghazwa*, with the same meaning), aimed at aggression against or revenge upon a rival tribe, and achieved by killing the enemy's fighting men (thereby crippling its power and ability to survive in the harsh environment of the desert) and by carrying off its camels or wealth and captives from it as slaves. These raids were always limited operations for a specific purpose, and the famous so-called 'wars' of pre-Islamic Arabia, such as those of Basūs (late 5th–early 6th centuries) and Dāhis (late 6th century), were in fact strings of small-scale campaigns spread over a period of many years, and not full-scale operations with set battles. Pre-Islamic Arabic poetry is imbued with the spirit of *fakhr*, glorying in the martial exploits of the tribe, and it lauds the heroic virtues of bravery and fortitude in battle. The ability to defend oneself was crucial to survival, for, as the poet Zuhayr ibn Abī Sulmā noted,

> Whoever is in terror of the ways Death may come, Death shall yet slay him, though he aspire to mount to heaven on the rungs of a ladder.
>
> Whoever suffers people always to be riding upon him, and never spares himself humiliation, shall come to rue it.
>
> Whoever defends not his water-tank with his goodly weapons will see it broken; whoever assaults not others is himself assaulted.