I
THE DEVELOPMENT OF SCIENCE IN ISLAM
From the 1st/7th to the 10th/16th Century

[1] IN AN INTRODUCTION to the present Catalogue it is a difficult task to convey to the reader an adequate idea of the importance of the Arab-Islamic culture area in the universal history of science. It is difficult, not only because only a modest part of the extant source material of manuscripts in Arabic, Persian and Turkish has been published and only a small portion analysed so far. There are various other reasons that render such an undertaking difficult. The reception and assimilation of Arab-Islamic science, right in the middle of its active phase, encountered hostility and violent rejection in the Occident as early as in the second half of the 7th/13th century. This hostile current, motivated to a large extent by religious zeal and sustained up to the 19th century in spite of some resistance, has deeply influenced the spirit and mode of presentation in the historiography of science in Europe since the 16th century. Influenced by this current, historians of science were led, noticeably for the first time in the 18th century, to a view of universal history, wherein the expression Renaissance automatically, by definition, resulted in the denial of any creative status for Arab-Islamic sciences in the intellectual history of mankind. In a crude periodisation of the history of science that is far removed from reality, the phenomenon called Renaissance¹ is conceived as an immediate continuation of the Greek period. In this chronological vault Arab-Islamic culture remains at best in the role of a transmitter through preservation and translation of certain Greek texts.

While the battle against the reception and assimilation of Arab-Islamic science, which had already begun in the 13th century, continued for a long time with full vigour, Arabist research emerged in some European countries in the 18th century directed towards understanding Islam together with its related cultural and intellectual wealth through the study of the sources. This discipline known as Arabic studies which, by nature, does not always display ideal traits and [2] lacks, not infrequently, objectivity in the interpretation and appraisal

Renaissance” (English translation, 1951, p. 128) and states: “The interpretation of the Renaissance and of the Middle Ages, which we now happen to be reading is not at all, as we would like to think, an historical hypothesis warranted by the facts. It is one of those fundamental positions which G. Séailles might have willingly gathered into his Affirmations de la conscience contemporaine. There is no discussing such an affirmation. It is not dictated by facts. It proceeds from the conscience; and it is the conscience that dictates the facts.”

“… A real fact, once eliminated, gives place to a feigned fact, created. Then one comments upon it, takes his stand upon it in order to eliminate from history all facts to which this phantom cannot be accommodated.” (ibid, p. 132). Cf. H. Schipperges, Ideologie und Historiographie des Arabismus, in: Sudhoff’s Archiv, Beihefte, Heft 1, Wiesbaden 1961, p. 14.

¹In his book Héloïse et Abélard (Paris 1938), the French philosopher Étienne Gilson speaks of a “professors’
of the subject of its study, has, nevertheless, achieved much in the course of its two centuries of history through numerous studies, editions and translations of sources, through the preparation of reference books as well as the collection and cataloguing of Arabic, Persian and Turkish manuscripts in European libraries. Although it was not able until now to challenge the prevailing depiction of the so-called “Renaissance” in history books, certain traces of revision are, however, visible thanks to the efforts of scholars like Jean-Jaques Sédillot (1777-1832) and his son Louis-Amélie (1808-1875), Joseph-Toussaint Reinaud (1795-1867), Franz Woepcke (1826-1864) or Eilhard Wie demann (1852-1928). To date George Sarton (1884-1956) has been the only historian of science who has made the effort to fully utilize the results of Arabist research. This he did in a masterly way in his Introduction to the History of Science. Unfortunately the conclusions he drew seem to have received too little attention in the historiographic works written subsequently on individual branches of the natural sciences. It is also regrettable that school books do not display any revision worth mentioning in the attitude inherited from the prevailing historiography of science. My generation grew up in a period when this attitude could assert itself with unshakable firmness in school books. A true revision can only be expected from future research conducted on a broad basis. However, the decisive factor in this process will be that the results of research become accessible to a wider circle of interested persons. An effective means of communication would be to make known the tools and instruments which were used, developed or invented within the framework of Arab-Islamic science and technology, and to reconstruct them if they are no longer available. Such communication is the goal of the present Catalogue and of the Museum the exhibits of which are described here.

After these introductory remarks, I move on to present an overview of the position of Arab-Islamic science in the context of the universal history of science.

The 1st/7th Century

As early as in the third decade after the advent of Islam, the state that was brought into existence by it extended its borders through conquests; in the north up to Asia Minor and western Persia and in the south-west down to Egypt. Through the capture of Damascus in the year 15/636, of Emessa (now Ḥims) and Aleppo in the year 16/637, of Antioch (now Antakya) in the year 17/638 and of Alexandria in the year 21/642, the Muslims came into lasting contact with the inhabitants of these cities who had belonged to what was formerly the Roman and later the Byzantine empire. It is well known that the conquerors treated the inhabitants of these traditional centres of learning well and knew how to profit from their knowledge and technical skills. Without such a policy it would be inconceivable that the Muslims [3] could have been able to seize the island of Cyprus as early as in the year 28/649 with an armada, pillaged on the coastline of Sicily in the year 31/652 and seized Rhodes shortly thereafter.3

Indeed, especially favourable circumstances existed for a gradual transition from conquerors to appropriators of the cultural wealth of their converted and non-converted fellow citizens, in particular, from the commencement of the Umayyad rule in 41/661. A surviving Arabic manuscript on alchemy claims to be a translation of a work by the Greek alchemist Zosimos (350-420) supposedly made as early as in 38/658.4 If we give credence to this statement, it would mean that the interest in translating Greek texts was already awakened in the

2 Published in 5 volumes, Baltimore 1927-1948.
4 ibid, vol. 4, p. 75.
governorship of Mu‘awiya I, who subsequently became the first Umayyad Caliph.

In the context of the history of mathematics, Julius Ruska explained in 1917 quite rightly the early willingness and the ability of the Arabs to absorb foreign cultural wealth: “It cannot be reiterated often and emphatically enough that the Arabs who flooded the Persian and Roman provinces brought with them neither ready-made jurisprudence nor state administration but were obliged to take over the administrative methods and legal procedures of the conquered regions without any basic change. That they succeeded, with amazing speed, in adapting themselves to the circumstances at large and in incorporating not only the state apparatus but also other fruits of an ancient, mature civilization is well known. This would indeed have been impossible had the intellectual distance between the conquering people and the contemporary Persians, Greeks and Egyptians been as great as it has been generally assumed until recent times. In particular, we should not treat the city-dwelling Arabs, who were the bearers of the intellectual and political movements, as semi-savages who had been, before Muhammad’s appearance, unreceptive to any cultural influences from the neighbouring peoples or that they were hardly literate in the very period in which they gained importance in the history of mathematics.”5

The inhabitants of the ancient cultural centres appear to have suffered no great difficulties in the course of their integration into the new society. Christian physicians, for example, were employed at the courts of the early Umayyad rulers. It is reported that one of them, Ibn Atâl by name served under Mu‘awiya I (r. 41/661-69/680). Another Christian physician, Abu l-Hakam, was also in Mu‘awiya’s service. He was entrusted by the ruler with the task of preparing medicines.6 In many areas of state administration, the Umayyads had to rely on the services and the support of the inhabitants of the conquered regions. Such collaboration seems to have functioned well. For a while local languages were still used in taxation and administrative practice; they were the Coptic language in Egypt, Greek in Syria, and Persian in Iraq and Persia. The use of the Arabic language for official records was introduced only later. In Syria, this happened at the instance of the ruler ‘Abdalmalik b. Marwân in 81/700, in Iraq on the orders of the governor al-Ḥaṣṣān b. Yūsuf in 78/697, in Egypt at the time of the governor ‘Abdalmalik b. Marwân in 87/705 and in north-eastern Persia (Ḫurāsān) under Caliph Hišām b. ‘Abdalmalik in 124/742.7

4 In the spirit of the already existing interest in the integration of the knowledge available in the cultural centres of the conquered regions, the first medical book was translated into Arabic under the Umayyad Marwân I (r. 64/683-65/685). It was the manual (Kunnās), written in Greek by the Alexandrian presbyter Ahron (flourished probably in the 6th cent. CE), which was first translated into Syriac by one Gōsiōs and then from this version rendered into Arabic by the Jewish physician Māsarāwaih of Baṣra, who expanded it with two chapters of his own. This translation is said to have been kept in the library of Caliph ‘Umar b. ‘Abdal‘azīz (r. 99/717-101/720), who made it accessible to the general public.8

From the first century of Islam and from the turn to the second, the titles of some translations into Arabic have come down to us. Several of these, including alchemical and astrological works, have been translated, as indicated in the manuscripts, upon commission by the Umayyad prince Ḥālid b. Yazid (d. ca.

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8 v. F. Sezgin, op. cit., vol. 3, pp. 5-6, 166-168, 206.
similar occurrences are reported by the great Islamic thinker al-Biruni (d. 440/1048). In his fundamental work on mathematical geography, Taḥdīd nihayāt al-amākin,\footnote{Ed. Cairo 1963, p. 268.} he mentions the fact that he saw in Ġazna, in modern Afghani-
stan, a book of astronomical tables (Zīg) written on old parchment with dates according to the
Diocletian Era, and that in an appendix there were additions by a scholar with records and
dates of solar eclipses that had been observed between 90 and 100 Ḥiğrā. He found in it, adds al-Birûnî, also references to the latitude of
the city of Bust and to the obliquity of the ecliptic.\footnote{v. F. Sezgin, op. cit., vol. 6, p. 122.}

[5] Of great importance for the early period of the reception was certainly the translation
of the alleged epistles of Aristotle to Alexander the Great, including the book περὶ χόμονου
under the Umayyad Hisâb b. ‘Abdalmalik (r. 105/724-125/743). With the translation of this
pseudo-text, which dates presumably from the second half of the 2nd century CE, the Arab-
Islamic culture area received a limited knowl-
edge of geography which however went beyond
the borders of the Islamic territory, of meteor-
ology differing from the native conception of
atmospheric phenomena as well as the funda-
mental Greek conception of the Earth: the Earth
is situated at the centre of the universe. The lat-
ter moves unceasingly, together with the entire
heavens. The fixed stars revolve together with
the heavens. The number of stars is unfathoma-
able for human beings. The planets are seven in
number. They differ from one another in their
nature and speed as also in their distance from
the Earth, and move on their own individual
orbits which lie one inside the other and are
enclosed by the sphere of the fixed stars.\footnote{v. F. Sezgin, op. cit., vol. 6, p. 72; Risālat Aristatālis
ila l-Iskandar fi l-‘ālam, MS Tehran, Dānīšgāh 5469 (fol. 36b-41b); H. Strohm, Aristoteles. Meteorologie. Über die
Welt, Berlin 1970, pp. 240-241.}
Introduction

Without wishing to amass further examples which, in any case, survive only in fragments and rather sparsely, we may draw attention here to an important feature of this early phase of reception which is characteristic of the entire period of reception and the assimilation of sciences in the Arab-Islamic culture area. The process of integrating foreign knowledge took place quite openly from the beginning, without any reservations and without any hidden motive which, as we shall see, was regrettably not the case with regard to the subsequent reception and assimilation of the Arab-Islamic sciences in Europe.

In 1965 Franz Rosenthal explained the motivation for the urge to acquire foreign knowledge in the following words:¹⁷ “Neither practical utilitarianism, however, which made an acquaintance with medicine, alchemy and the exact sciences appear desirable to Muslims, nor theoretical utilitarianism which prompted them to occupy themselves with philosophical-theological problems, might have sufficed to support an extensive translation activity, had not the religion of Muhammad stressed from the very beginning the role of knowledge (‘ilm) as the driving force in religion and, thereby, in all human life … Without this central position of ‘knowledge’ in Islam and the almost religious veneration extended to it, the translation activity would presumably have been less scientific, less scholarly and less extensive. It would probably have been confined to the absolutely essential and immediately useful to a much greater degree.”

The progress in the field of science achieved quite early in the young Islamic society of the first century with regard to the wealth of knowledge of foreign provenance, took not only place through the translation of books, of course. The circumstances arising out of the new religion, which were certainly not so primitive as is often assumed, quickly induced the Arabs to engage themselves with new intellectual challenges; in particular, there arose an astounding urge towards the art of writing. Going through the relevant sources, one is given the impression that towards the end of the 1st/7th century the level of literacy of the people in the Islamic territory reached a degree that had no comparison in the contemporary Middle Ages. The variants found in [6] the copies of the Quran circulating immediately after the Prophet’s death urged the Muslims to prepare a universally acceptable version of the Quran. That was a philological task. The interpretation of many uncommon words in the Quran led not only to the emergence of the first commentaries on the Quran but also awakened the interest in lexicography. Likewise, quite early on, a significant philological tool was established in the use of poetic material as linguistic evidence. This recognition resulted in an appropriate appreciation of the poems of the pre-Islamic period and of the period of transition to Islam, and led to the activity of collecting and preserving the poetic material available in book form or in fragments. Over the course of centuries, the philological achievements which commenced with the simple interpretation of the Quranic vocabulary developed to such a height that—with regard to the inner principles as also to the outer extent—they “could be compared only with those of the Chinese.”¹⁸

The Arabic sources assign the beginnings of Arabic grammar also to the 1st/7th century. Only with such an early start can the enormous development of the 2nd/8th century be understood.

The intense activity of collection and preservation in writing of the sayings of the Prophet (hadīth) led to a special manner of transmission, the principles and rules of which have often been misunderstood by modern scholars.


¹⁸ v. F. Sezgin, op. cit., vol. 8, p. 15.
The quest of recording in writing the Prophet’s biography and his conquering expeditions as well as the biographies of his successors paved the way to the development of a variegated historiography of enormous proportions, including the separate treatment of the history of science that emerged quite early on as well. To my knowledge the issue of the significance of this historiography, which arose in a purely Islamic intellectual milieu, and of the methodology developed within it has not at all or at least not adequately been treated as yet in the context of the universal history of the subject. Even Arabists underestimate the historical content of the majority of the historical writings that arose primarily in the first three centuries of Islam (7th-9th cent. CE) because of the peculiar method of quoting their sources. The individual historical reports (habar, pl. ahbār) in those works which are, in most cases, preceded by a chain of transmitters as evidence of their authenticity, and which can, in some cases, be accompanied by the respective authors’ own remarks or comments, are unfortunately considered, either as reports that were handed down orally for centuries, or as personal views of a particular transmitter written down according to certain tendencies one or two generations before the book in question was composed. Without going into further details in this introduction, it may be stated that those chains of transmitters contain the names of the authors of written sources as well as their transmitters, who were authorized, according to strict rules, to hand down certain named sources.\(^{39}\) In modern terms, the chains of transmitters appearing in Arabic works on history can be considered as references to the sources, somewhat like those given in the footnotes of our books.

The earliest written sources of juridical themes are likewise to be sought in the 1st/7th century and as early as in the first half. Naturally in these early records of modest extent only individual themes are treated. More extensive compendia of Islamic law, with a systematic approach to the matter, [7] began to appear in the first half of the 2nd/8th century.\(^{20}\)

The process of reception of foreign knowledge and culture developed rapidly in the first half of the 2nd/8th century qualitatively as well as quantitatively and extended to almost all areas of knowledge of that time. The sources used comprised not only Greek works in direct translation or mediated by a Syriac translation, but also Middle Persian texts.

An important feature of the early translations from the Greek consisted in the fact that they were pseudo-epigraphs; thus they bore the names of well known authorities from Antiquity like Aristotle, Socrates or Ptolemy as ostensible authors. These arose in the tradition of the pseudo-epigraphic Greek literature which can be traced back at least to the 2nd century BCE. The content of the pseudo-epigraphs preserved in Arabic translation creates the impression that most of them were produced in late antiquity, shortly before the rise of Islam. They show the state of experience and the developments of the period of their origin and appear to emanate mainly from the eastern regions adjoining the Mediterranean Sea. The reason why very few of these pseudo-epigraphs translated into Arabic are extant in the Greek original in full or in part lies, in my view, in the fact that the majority of them were produced just before the advent of Islam in such cultural centres that were to become part of the Islamic territory as early as in the first half of the 1st/7th century. Once they were translated, further preservation of the Greek originals was left to chance. Naturally neither the translators nor the readers knew or were in a position to know that the writings bear the names of fictitious authors. Arab-Islamic scholars quoted these titles as true writings of their alleged authors, even after the original writings of those


\(^{20}\) ibid, vol. 1, pp. 393 ff.
authors became available in Greek and in Arabic translation. They became acquainted with, for example, the pseudo-writings of Aristotle, Plato or Ptolemy, before they knew their real works, and used one or the other side by side as of equal merit. Many of these books were translated subsequently as the work of their pseudo-authors, from the Arabic into Hebrew and Latin and were then regarded as authentic for centuries in the Occident as well.

In my Geschichte des arabischen Schrifttums, I have discussed on several occasions the question of the period of origin and the significance of these pseudographs attributed to Greek, Babylonian, Persian or other authors and preserved in Arabic writings in part or in full. While referring to my discussion therein, I limit myself here to the remark that most Arabists consider these not as translations but as forgeries by Arab-Islamic scholars. This would mean that these scholars first composed the pseudo-writings themselves in order to cite them subsequently as real, as is the case particularly in the earliest Arabic texts. In this scenario the question remains open whether the Arabs and early Muslims, given their geographical and cultural-historical circumstances, were in the position at all of inventing the contents of those writings which were, in part, very extensive. Through the late dating and the devaluation of these pre-Islamic pseudographs preserved in the body of Arabic literature, important material for the history of science of late antiquity is, unfortunately, lost.

[8] The 2nd/8th Century

The range of reception from the adjacent civilizations was substantially increased in the second half of 2nd/8th century. Receptivity also developed steadily and quickly thanks to many favourable circumstances. As regards the process of reception, one should not, of course, think merely of books and their influence. In the role played for some time by the representatives of the cultural centres of the conquered lands of the Eastern Mediterranean area as teachers of the Muslims, the position of the conveyors of knowledge and culture of the vanquished Persian-speaking area is particularly remarkable.

We are quite well informed about the reception of foreign knowledge under the Sassanids, particularly under Sâpûr I (r. 242-272). The scientific knowledge borrowed mainly from the Greeks and Indians, and probably also indirectly from the later Babylonians, received some impetus here. In connection with the area of knowledge cultivated in the Sassanid Empire in a rather syncretistic manner, we can notice an accelerated process of reception on the part of the Arabs in the fields of astronomy, astrology, mathematics, geography, philosophy and medicine. We may cite here three events from astronomy, philosophy and medicine illustrating this development.

The revision of the astronomical tables in the Canon of Ptolemy with the help of Indian tables resulted in certain corrections. The youngest redaction of this revision, commissioned by Yazdagird III (r. 632-651), was translated into Arabic under the title Zīg aš-šahrīyār probably in the first half of the 2nd/8th century. It seems to have had quite a stimulating effect on Arab-Islamic scholars so that they occupied themselves with scientific astronomy at an early stage.

In the field of philosophy, some parts of the Aristotelian Organon in Middle Persian translations were rendered into Arabic by ‘Abdallâh Ibn al-Muqaffa’ (d. 139/756). Ibn al-Muqaffa’

\[v. \text{ibid, vol. 6, p. 106 ff.}\]
\[v. \text{ibid, vol. 5, pp. 203-204; vol. 6, pp. 107-110, 115.}\]
\[v. \text{ibid, vol. 7, p. 322; in greater detail in the manuscript of the chapter on light and popular literature, of the Geschichte des arabischen Schrifttums, which was prepared some 20 years ago.}\]
was of Persian descent and one of the most eminent writers of his time. He influenced the course of the reception through translations of Persian books from various branches of knowledge, besides through his own works. Among others, there was his translation of the *Kalila wa-Dimna*, a mirror of princes in the form of animal fables which is said to have been translated previously from Sanskrit by the Persian Burzöe under Ḫusraw I Anūṣirwān (r. 531-579). The introduction added by Burzöe contains one of the oldest extant discourses concerning medical ethics and is, at the same time, the autobiography of a physician.²⁶

As to the reception of medicine in a narrower sense in the first half of the 2nd/8th century, we may mention that the famous Sassanid centre of knowledge, Ḫundišāpūr, was intact at least until the time of Caliph al-Ma’mūn (r. 198/813-218/833) and that the physicians from this place were also in touch with Baghdad. It is reported that Ġūrgis b. Ġibril b. Buḥtīṣū’, a chief physician in the hospital of Ḫundišāpūr and author of medical works, was called at an advanced age, in the year 148/765, to Baghdad by Caliph al-Mansūr to cure his stomach ailment. Moreover, he is said to have [9] translated several medical books from the Greek into Arabic. For his own works he used the Syriac language.²⁷

The progress that can be seen in the humanities of the Arab-Islamic culture area in the first half of the 2nd/8th century was immense. Writings on the sciences of tradition (hadīt) and jurisprudence, which hitherto had been limited to single topics, developed into voluminous manuals, divided into subjects. Moreover, the methodology of the science of tradition became more refined. Historiography also gained in breadth and content. In books on the history of conquests, the geographical descriptions of the countries concerned were given adequate space.

The development of the above-mentioned branches of philology was remarkably lively in the first half of the 2nd/8th century. This is true of the collection and codification of Old Arabic poetry and also of the extension of the scope of the material discussed in the fields of grammar and of the development of lexicography. If we take, for instance, the achievements of a man like al-Ḥalil b. Ahmad, his important role in the development of lexicography and grammar and in the formation of theory on poetic metres and music is stressed. He was possibly the first to write a comprehensive work on the basis of numerous monographs by his predecessors. Certainly, his *Kitāb al-ʿAin* was assigned the importance of a canonical work of lexicography quite early on.²⁸

While the process of reception continued in all intensity in the second half of the 2nd/8th century and also still in the following century, the period of assimilation began at the same time. Important in this connection is the fact that Caliph al-Mansūr (r. 136/754-158/775) commissioned the translation of the voluminous astronomical *Siddhānta* from Sanskrit into Arabic. The commission was executed by one of the youngest representatives of Sasanid astronomy in Islam, al-Fazārī, in the year 154/770.²⁹ It is remarkable for those times that there existed not only adequate pre-requisites—including the necessary Arabic terminology for translating the astronomical-mathematical topics—but also the fact that al-Fazārī and his contemporary Yaʿqūb b. Ṭāriq were already capable of discussing, in several treatises of their own, topics of both theoretical and also applied astronomy. They wrote, inter alia, about the use of the planispheric astrolabe and the armillary sphere.³⁰ I consider this to be the

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²⁸ v. F. Sezgin, op. cit., vol. 8, pp. 51-56
²⁹ v. ibid, vol. 6, p. 122.
beginning of the phase of assimilation in the field of astronomy.

The desire of the statesman and scientist Yahyā b. Ḥālid al-Barmakī (b. 120/738; d. 190/805) to have Ptolemy’s *Almagest* translated into Arabic should also be understood in that sense. His desire was fulfilled apparently twenty-five years after the translation of the Indian *Siddhānta*. To judge how high a standard of astronomical learning and science in general had been achieved in the Arab-Islamic culture area by this time, it is revealing to note that the patron was not satisfied with this first translation and commissioned a fresh translation from other scholars.

An even more distinct sign for the beginning of the period of assimilation can be observed in the field of chemistry–alchemy. Several scholars writing in Arabic composed books in this field during the second half of the 2nd/8th century, mostly by following in the wake of the authors of books already translated. One can, of course, consider this to be an assimilation of a modest scale. However, this is not what we have in mind here, but rather the phenomenal appearance of a scholar by the name of Gābir b. Ḥaiyān, who in the same period developed from chemist and alchemist to natural philosopher and occupied himself with almost all the areas of knowledge of his time. As we shall show in greater detail in the relevant chapter, his extant treatises numbering several hundred demonstrate that he built primarily upon the knowledge that became accessible in the pseudographs. His writings, the chronological sequence of which can be established with the help of the numerous cross-references in his own works, reveal an extraordinary scientific career. In the field of chemistry–alchemy he appears as a scientist intent on establishing a discipline dedicated to the qualitative analysis of substances found in nature by determining their quantitative proportions. According to him, all elements of human knowledge can be traced back to a system of quantity and measurement that leads to a principle of equilibrium which he calls the “law of measurements” (‘ilm al-mīzān). At the beginning of his career, Gābir appeared as one of the protagonists in the process of assimilation but soon developed into a bold and highly creative natural philosopher (infra vol. IV, 99ff.).

The simultaneous progress in the field of the humanities also proceeded at an amazing pace. Each scholar built upon the works of his predecessors, extended them as well as he could and thus rendered those works, to some extent, dispensable. An example of this is the book of grammar, “The Book” (*al-Kitāb*) by ‘Amr b. ‘Uṯmān Sibawaih (d. probably 180/796). This monumental work, considered by later generations as the canon of grammar, through its size and systematic structure bears evidence of the fast and substantial development of the sciences in Arab-Islamic culture within a short span of time.

**The 3rd/9th Century**

In the first two decades of the 3rd/9th century, the process of development of the sciences assumes a completely new character which can be considered the beginning of the period of creativity. While the sciences cultivated in the Islamic world were still able to profit in their constant qualitative and quantitative development from the favourable conditions of the preceding century so that they could continue their way into the 3rd/9th century at an undisturbed pace, they received in its first decades additional, entirely new impulses through Caliph al-Ma‘mūn (r. 198/813-218/833). As an admirer of Greek science, this ruler had Greek books from Byzantium and from the conquered cultural centres brought to Baghdad and commissioned translations into Arabic not only of works that had not previously been translated,

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31 v. F. Sezgin, op. cit., vol. 6, p. 85.

32 v. ibid, vol. 9, pp. 51-63.
but saw to it that many of the older translations were revised.

According to our not yet very detailed knowledge, al-Ma’mūn seems to have facilitated and organized the work of his scholars through an institution named “House of Wisdom” (Bait al-hikma). The Caliph himself was knowledgeable in various branches of science. Several important works were produced upon his incentive and oftentimes he was personally involved in the projects. Some of his achievements may be mentioned here, in so far as they show a creative character in the sense that he was not content with a result but wanted to go beyond it.

Thus he had the astronomical data in the πρόχειροι κανόνες by Ptolemy (which had been [11] introduced at the time of the first translation of the Almagest into Arabic) verified and corrected by his astronomers. The results of this enterprise were published under the title az-Z¬™ al-mumtaΩan.

One of the tasks that the Caliph performed together with his astronomers was the calculation of the longitudinal difference between Baghdad and Mecca in order to determine the direction of prayer (qibla) as precisely as possible. Here it must be noted that the Caliph did not want to rely on the coordinates of the two cities already known from various tables, but attempted to determine the longitudinal difference from his own observations at the time of a lunar eclipse. The longitudinal difference of 3° thus calculated (actually 4°37′) was reasonably accurate.34

For the future attempts to determine the surface area of the Earth mathematically, it was of fundamental importance that on al-Ma’mūn’s order the task of an accurate measurement of the length of one degree of the meridian was accomplished. A group of his astronomers, using instruments for determining the position of the sun as well as for the precise direction of the meridian and with the help of ropes and sticks, took repeated measurements in the plains of Syria and Iraq and arrived at a value for the length of one degree on the meridian of between 56 1/3 and 57 Arabic miles, establishing 56 2/3 as a mean. This result differs only slightly from the modern value. In Carlo A. Nalino’s view, this was—compared with the determination by Eratosthenes which was based on several uncertain assumptions—the first strictly scientific measurement of the Earth, being the result of a time-consuming, strenuous task.35 Furthermore, the Caliph used the opportunity of his expedition against Byzantium to have the length of a degree of the meridian once more determined by trigonometric means. From a point on the sea shore which was high above sea level, he let the astronomer Sind b. ‘Ali, who accompanied him, measure the depression of the sun at sunset in order to calculate trigonometrically the length of the Earth’s radius. This is the very procedure that was later associated with the names of Francesco Maurolico (1558), Sylvius Belli (1565) and Francesco Giuntini (d. 1580).

Caliph al-Ma’mūn’s strong interest in astronomy and its development led him to build an astronomical observatory first in the Ţammāsiya quarter in Baghdad and thereafter another one on the Qāsiyün, the local mountain of Damascus. By the use of large instruments and continuous observations he endeavoured to obtain measurements more precise than those of his predecessors. Apparently he was the first in the history of astronomy to establish astronomical observatories in the strict sense of the word.

Finally, we shall mention that project initiated by al-Ma’mūn which can be considered, without any doubt, the most significant and the most consequential for posterity. This

33 v. F. Sezgin, op. cit., vol. 6, pp. 136-137.
34 v. ibid, vol. 10, p. 94.
35 v. ibid, vol. 10, p. 95.
36 v. ibid, vol. 10, p. 96.
project belongs to the fields of geography and cartography.

After attaining not inconsiderable familiarity with longitudes and latitudes, maps and the geography of countries, scholars in the Arab-Islamic culture area translated Ptolemy’s *Geographike ὑφήγησις* into Arabic. In addition to this, at the beginning of the 3rd/9th century Arab-Islamic scholars became acquainted with the geography and maps of Marinus (1st half of the 2nd century CE). In connection, al-Ma’mūn decided to commission a geographical work with a world map and regional maps, and entrusted this task to a group of scholars. It goes without saying that the latter relied primarily on Ptolemy’s Geography which, for its part, was more of a cartography manual than a book on geography. It contained the coordinates of approximately 8000 localities which, with very few exceptions, were not data obtained by astronomical measurement. The coordinates were gathered mostly from the Geography and the maps of Marinus and elaborated further.

The world map discovered about twenty years ago and the surviving regional maps of al-Ma’mūn’s geographers together with contemporary tables of coordinates based on these maps open up an entirely new horizon for the history of cartography. Required is, however, the willingness of historians to approach this material without any bias. I have presented my own appraisal in the study *Mathematische Geographie und Kartographie im Islam und ihr Fortleben im Abendland* (constituting volumes 10 and 11 of my *Geschichte des arabischen Schrifttums*) which appeared in 2000, and shall present some crucial points thereof in the cartographic section of the present Catalogue. In this general overview of the position of the Arab-Islamic culture in the universal history of science, I should like to state, instead, the fundamental convictions I have reached during the many years of my occupation with this topic. As great as the efforts of the astronomers and geographers working for al-Ma’mūn may have been, their achievements naturally remained within narrow confines. This had been the case with their Greek predecessors and it was to be true for their successors in the Occident. We must not indulge any more in the naïve and forced attitudes of the history of cartography, such as the notion that at the beginning of the 14th century a priest like Giovanni Carignano should have been in the position to produce at his abode in Genoa, just on the basis of enquiries, a world map with an almost correct depiction of the Mediterranean Sea, the Black Sea, the Caspian Sea and Anatolia, without knowing or using as models the maps made on location by generations of people living there. Or the assumption, to give another example, that in the year 1724 Guillaume Delisle could have, at his studio in Paris, succeeded in drawing the first almost perfect map of Persia with Eastern Anatolia and the Caucasus with hundreds of localities and their coordinates, with the configurations of oceans and lakes, with the outlines of countries and the courses of rivers, without having translated into his mother tongue as a model a native map on which generations had worked.

On the basis of this reality and supported by historical facts, we see that the Ma’mūn geographers substantially improved the cartographic depictions inherited from their predecessors. Their progress can be measured against a world map reconstructed according to the data of Ptolemaic geography by the Byzantine scholar Maximus Planudes around 1300 CE. The scholars working for al-Ma’mūn had the advantage

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38 v. ibid, vol. 10, p. 30 ff.
40 v. ibid, vol. 10, p. 32 ff.
41 v. ibid, vol. 10, p. 413 ff.
of surveying from Baghdad, which was at that time quite the centre of the inhabited world, South and Central Asia, East and North Africa, relying, as far as possible, on their own observations and measurements. The Ma’mūn map is of epochal importance to us for various reasons. Leaving aside some features of the first vulgata which are not traceable any more, the Ma’mūn map, together with the map reconstructed on the basis of its book of coordinates, reflects the achievements of humankind in the first quarter of the 3rd/9th century regarding the cartographic [13] depiction of the Earth’s surface. Thus it provides us with a solid base for the judgement of the further development in which this map itself was of great significance both in the Arab-Islamic culture area as well as in the Occident. Besides its quite elaborate depiction of the Earth’s surface, the cartographic techniques used, such as globular projection, cartographic scale and depiction of mountains in perspective, help us to establish a much earlier date for their introduction.

Mathematics, which already had made substantial progress in the second half of the 2nd/8th century, particularly after the introduction of the notion of “zero” with the translation of the Indian Siddhánta into Arabic, was enriched in the first two decades of the 3rd/9th century by the almost simultaneous appearance of three works on algebra. Their authors were Muhammad b. Mūsā al-Ḥwārizmī,42 Sind b. ‘Ali43 and Abdalhamīd b. Wāsī‘ Ibn Turk.44 The works were called the Kitāb al-Ğabr wa-l-muqābala, which means “reconstruction and juxtaposition”. These were the first treatments of algebraic linear and quadratic equations, independent of arithmetic. Al-Ḥwārizmī states that he wrote his book on commission by Caliph al-Ma’mūn. All three works seem to be based on a syncretistic tradition which had evolved in the Hellenistic Orient, absorbing Greek, Indian and late-Babylonian elements directly or indirectly. The algebra of al-Ḥwārizmī and his arithmetic have, after their translation into Latin, deeply influenced mathematics in the Occident since the 12th century.45

Towards the end of the first half of the 3rd/9th century, mathematics in Islam seems to have reached the threshold of its period of creativity. Characteristic evidence of this phenomenon can be found in the works of the Banū Mūsā (namely, Muhammad, Ahmad and al-Ḥasan, sons of Mūsā b. Ṣākir). At the time when they were occupied with mathematics, the most eminent works in the field, like those of Euclid, Archimedes, Apollonius, Menelaus and others, were already available. The terminological difficulties had been solved to a large extent. The content of Euclid’s Elements had been completely assimilated through commentaries written three quarters of a century earlier. With avid interest, older contemporaries of the Banū Mūsā had devoted monographs to the deductive geometry of the Greeks, and through their own monographs the three brothers continued the task thus begun. The works that have come down to us bear witness of their ability to deal with the works of their Greek predecessors in a creative and undaunted manner; how much they really accomplished is not crucial. In their work on geometry they claim to have found a new solution for the trisection of angles. To that end they used a figure which, in a further developed form, became later known as “Pascal’s limaçon.” The extent of their own accomplishment is less decisive for our judgment than the attitude. The three brothers also undertook mensuration of the circle according to the method developed by Archimedes. They tried hard “to distance themselves as far as possible from their Greek masters by using a different method of proof and by choosing oth-

43 v. ibid, vol. 5, pp. 242-243.
45 v. ibid, vol. 5, p. 28.
er letters of the alphabet."\textsuperscript{46} They knew Heron’s theorem \([14]\) for the area of a triangle, yet they used another proof, influenced perhaps by the geometry of Late Antiquity. Moreover, they were also able to extract the cube root of a non-cube number quite accurately in sexagesimal fractions.\textsuperscript{47}

The natural philosopher Ya‘qūb b. ʿIṣḥāq al-Kindī (d. shortly after 256/870), a contemporary of the Banū Mūsā, offers interesting clues for the beginning of the period of creativity in the field of meteorology. He deals with all the topics of Aristotelian meteorology following Aristotle and his disciple Theophrastus, but for many problems he provides independent and original explanations, as for instance, on the origin of wind.\textsuperscript{49} Being a physicist, he draws on the law of extension: The volume of all bodies shrinks in proportion to the degree of coldness and expands in proportion to the degree of heat. Thus he finds the explanation for the appearance of wind, stating: “Air moves from regions in which heat expands [the air] in the direction of regions where coldness shrinks [it].”\textsuperscript{50} At the time when the Sun stands above the northern hemisphere of the Earth, he goes on to say, the air expands because of the heat and streams southwards where it contracts because of the cold prevailing there. He concludes that was why most of the winds in summer blow from the north, but in winter the other way round, unless changes of directions occur owing to topographical conditions and other side effects. This explanation of al-Kindī for the origin of winds and for their direction is almost identical with the modern theory, the precursors of which are purportedly George Hadley (1685-1744) and Immanuel Kant (1724-1804).\textsuperscript{51}

It appears that the beginnings of the modern explanation of the causes of ebb tides and flood tides are also to be sought in the first part of the 3rd/9th century. The natural philosopher ʿAmar b. Bahr al-Ḡāhīz (d. 255/888) transmits the view that low and high tides correspond to the measure of the pull and the push of the moon upon water.\textsuperscript{52} This view was formulated more precisely by one of his successors: “the moon behaves towards the sea as the magnet behaves towards iron ore, the former pulling the latter towards itself, in whichever way it turns.”\textsuperscript{53}

The advances in natural sciences, which we have outlined above on the basis of a few examples, were not inferior to those in the humanities. Yet in the historic presentation of these fields an unfortunate and counterproductive view developed, propounded by a group of Arabists who have the tendency to assign only to this phase, viz. the first half of the 3rd/9th century, the beginning of the codification of the literary, poetic, legal, historical, theological and philological texts of all earlier generations since pre-Islamic times. The exponents of this tendency claim to have convinced themselves that the authors of the works emerging in this period were the first to commit to writing the materials that had been handed down orally until then. By contrast, it must be held that the written products of this period \([15]\) were mainly aimed at expanding and enhancing the systematic structure, as well as the selection and interpretation; that is to say, they were meant to be supplements in the widest sense and, though they brought forth new literary genres,


\textsuperscript{49} v. ibid, vol. 7, p. 242.

\textsuperscript{50} v. ibid, vol. 7, p. 242.


\textsuperscript{52} v. ibid, vol. 7, p. 241.

\textsuperscript{53} v. ibid, vol. 7, p. 304.
were intended to continue preceding literary traditions. Characteristic in this sense were the mathematical disputations between the atomists and their adversaries carried out with all virtuosity in theological-dialectical works in the second half of the 2nd/8th century and during the following century.\textsuperscript{54}

The second half of the 3rd/9th century saw an increase in the signs of creative independence. In the field of astronomy significant progress was made in gnomonics and in the practical study of construction methods for sundials which had started already at the beginning of the century. Al-Kindi determined the azimuth in a different way to his predecessor Ptolemy. His younger contemporary, al-Māhānī, who dealt briefly with the same problem in the second half of the 3rd/9th century, departed even more than al-Kindi from descriptive geometry and used for the most part a purely graphic method. The computational method for the determination of the azimuth and shadow lengths required for the point-by-point construction of sundials gained more and more importance over the graphic method from the last quarter of the 3rd/9th century. Tābit b. Qurra and his grandson Ibrāhīm b. Sinān, proponents of this school of a computational solution, discovered the curvature of the hour lines, drawn point-by-point on horizontal dials. The proof devised by Ibrāhīm is the same as that by Christoph Clavius\textsuperscript{55} (1537-1612) and Jean-Baptist Delambre (1749-1822).\textsuperscript{56}

Tābit b. Qurra (d. 288/901) contributed an improved value for the precession of the equinoxes. It is 1° in 66 years, i.e. 55" in one year, as compared to 1° in one hundred years or 36" in one year for Ptolemy and Hipparch. Subsequent astronomers introduced further improvements, so that Naṣīriddin at-Ṭūsī (d. 672/1274) was able to calculate a value of 1° in 70 years or 51" per year which comes already very close to the value of 1° in 72 years held in modern times.\textsuperscript{57}

In the course of his observations, Tābit b. Qurra was the first to notice that the sun’s apogee moves in the same direction as the signs of the zodiac.\textsuperscript{58} A precise definition of the extremes of acceleration and deceleration in this motion was arrived at by al-Bīrūnī towards the end of the 4th/10th century.\textsuperscript{59} The value for the apogee’s progression was determined towards the end of the 5th/11th century by the Andalusian astronomer Ibrāhīm b. Yaḥyā az-Zarqālī with 1° in 279 years, corresponding to 12.09" in one year, which is quite close to the modern value of 11.46".\textsuperscript{60}

Towards the end of the 3rd/9th century, Abu l-‘Abbās al-İrānshahrī defended the possibility of an annular solar eclipse against Ptolemy and expressed the view that a total solar eclipse can occur only at a medium distance and not at the maximum distance of the Sun from the Earth.\textsuperscript{61} In the Occident, an annular eclipse was observed by Chr. Clavius in the year 1567.\textsuperscript{62}

[16] The geographer ʿAbd al-Ḥamīd b. ʿUmar Rustah,\textsuperscript{63} who flourished in the second half of the 3rd/9th century, mentions amongst the cosmological and astronomical theories known to him, the notion that the Earth was not situated in the centre of the universe and that it was not the Sun and the spheres which rotate but the

\textsuperscript{54} v. F. Sezgin, op. cit., vol. 5, pp. 29-30.
\textsuperscript{56} v. F. Sezgin, op. cit., vol. 6, pp. 23-24.
\textsuperscript{57} v. ibid, vol. 6, p. 26.
\textsuperscript{59} v. F. Sezgin, op. cit., vol. 6, p. 263.
\textsuperscript{60} v. ibid, vol. 6, p. 27.
\textsuperscript{61} v. ibid, vol. 6, p. 173.
\textsuperscript{62} v. Matthias Schramm, Ibn al Haythams Weg zur Physik, Wiesbaden 1963, p. 27.
Earth. We would very much like to know where this vision of a heliocentric system came from. He further reports on a theory to the effect that the universe is infinite and that the Earth, as part thereof, is in an infinite falling motion.

The invention of the first astronomical instruments in the Arab-Islamic culture area occurred in the last quarter of the century. One of these was the spherical astrolabe, the invention of which is attributed to Ǧābir b. Sinān al-Ḥarrānī64 (infra vol. II, 120 f.). His contemporary al-Šaṣī b. Ḥātim an-Nairīzī claims to be the first to have invented instruments with which the distance between objects situated in the atmosphere or projecting from the Earth’s surface can be measured.65

The mathematician and astronomer Muḥammad b. ʿĪsā al-Māhānī (lived possibly up to 275/888) took a crucial step forward in the history of mathematics when he reduced a problem which could not be solved with a pair of dividers and a ruler to an equation of the third degree. However, he did not succeed in solving the equation.66 Al-Māhānī was also the first mathematician to arrive at a method of using the law of the spherical cosine for the mathematical determination of the azimuth when he calculated one of the angles of a spherical triangle from its sides. As Paul Luckey67 was able to demonstrate in 1948, al-Māhānī was a forerunner of Johannes Regiomontanus (1436-1476) in this respect.

In the second half of the 3rd/9th century Tābit b. Qurra achieved outstanding results not only in astronomy but in mathematics as well. He generalized the theorem of Pythagoras for all triangles; in the Occident, however, the relevant theorem bears the name of John Wallis (1616-1703).68 Without being aware of the results already achieved by Archimedes in this area, Tābit made use of infinitesimal calculus in his two treatises on the quadrature of the parabola and on the cubature of the paraboloid. His quadrature of the parabola corresponds to the calculation of the integral \(\int_0^a \sqrt{px} \, dx\). Through a brilliant step which he applied there, “the summation of integrals that had fallen into oblivion was revived; and with its help Ibn Qurra calculated, indeed for the first time, an integral of the power \(x^n\), for a fractional exponent, namely, where he, again for the first time, undertook \(\int_0^a x^m \, dx\) the division of the integration interval into unequal units. In the middle of the 17th century, P. de Fermat undertook the quadrature of the curves \(y = x^m/n\) for \(m/n < 1\) through a similar procedure, where he divided for the abscissas into units forming a geometrical progression.”69 Tābit’s procedure for the calculation of the volume of paraboloids also differs substantially from that of Archimedes. His calculation of the volumes of domes with pointed or depressed crowns gained [17] by the rotation of a parabola around a secondary axis is also novel, whereas Archimedes merely dealt with the rotation of paraboloids with an axis of rotation identical to the axis of the parabola.70

His contemporary Ḥabaš al-Ḥāṣib already applied a kind of iterative algorithm in the calculation of the lunar parallax. The equation in question resembles the one later introduced by Johannes Kepler (1571-1630) in connection with his theory of planetary motion.71 Ḥabaš

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64 v. F. Sezgin, op. cit., vol. 6, p. 162.
65 v. ibid., vol. 5, p. 268-269.
66 v. ibid., vol. 5, p. 260.
70 v. E. S. Kennedy, W. R. Transue, A medieval iter-
was perhaps also the first mathematician and astronomer to prepare a table of cosecants (qudr az-zi'll), comprising $1^\circ$–$90^\circ$, yet his Arabic successors did not emulate him as they obviously realized that secants and cosecants were dispensable for their trigonometric calculations. In the Occident, Nicolaus Copernicus (1473–1543) was the first to compile tables of secants, yet here too they disappeared from trigonometry from the 17th century onwards after their dispensability became obvious.

A comparison between the work on algebra by Abū Kāmil Şu Sağa‘ b. Aslam (written apparently in the last quarter of the 3rd/9th century) and those of his predecessors (which appeared in the sixties and seventies) shows that this subject must have undergone a rapid development in the regions of Islam during the second half of the century. Even though Abū Kāmil, like his predecessors, does not go beyond linear and quadratic equations, it becomes obvious in his case that he had traversed a long distance on the way towards arithmetisation and that the theoretical part had grown copiously in his work. In the application of the procedure of geometrical proof, we find him abandoning the demand for faithfulness to dimensions: He speaks of proportions but makes no distinction between commensurable and incommensurable units. With him the reluctance to tackle the irrational, noticeable among the Greeks, disappears. To the three quantities enumerated by al-Ḥwārizmī—numbers, roots and squares—he adds the unknowns up to the seventh power.

Together with al-Ḥwārizmī, Abū Kāmil belongs to those Arab-Islamic scholars who brought about a profound effect in the Occident through Hebrew and Latin translations of their works. “The longest lasting influence on subsequent Occidental mathematicians he exerted through the mediation of Leonardo of Pisa, who made ample use of Abū Kāmil’s ‘algebra’ in his Liber abaci.” Leonardo adopted some problems even in the same wording.

Medicine and pharmacy also developed remarkably in the second half of the 3rd/9th century. Abū Bakr ar-Rāzī (b. ca. 251/1165; d. 313/925) was the most important among the numerous physicians of that period. Through his extensive Kitāb al-Ḥawi (Latin: Liber continentens) and numerous other works, he not only influenced the medicine and pharmacy of his own cultural area but also became, via translations of many of his books into Hebrew and Latin, an undisputed authority in Western medicine right up to the 17th century. Moreover, after Gābir b. Haiyān, he was the next, as far as we know, to have criticized several points of Galen’s medicine. His surviving “Doubts” on Galen are of great interest for the history of medicine.
Julius Hirschberg,85 the eminent authority on Arabic ophthalmology, drew attention to the fact that ar-Rāzī in his Kitāb at-Tīb al-Mansūrī, was the first to speak of the contraction of the pupil upon exposure to light. Not only from the medical point of view but also from the history of optics, it is of epochal significance that ar-Rāzī in his treatise on optical perception and in his critique of Galen refuted Euclid’s and Galen’s theory of vision, according to which the process of seeing relies on rays emanating from the eye.86

In the field of chemistry-alchemy, ar-Rāzī, building upon Gābir’s work, produced a body of literature mainly to serve practical requirements with brief descriptions of the substances, apparatuses and processes.

At the same time, i.e., in the second half of the 3rd/9th century, in the field of geography, a distinct anthropogeography developed from the genre of histories of cities and conquests that had already emerged in the preceding period. Examples are the Kitāb al-Amsār wa-ʿāgāʾib al-buldān87 by the natural philosopher and polymath ʿAmr b. Bahr al-Ḡāḥī (d. 255/868), the Kitāb al-Masālik wa-l-mamlāk88 by ʿUbādallāh b. ʿAbdallāh Ibn Ḥurradādhīb (d. after 289/902) and the Kitāb al-Buldān89 by Ahmad b. Ḥishāq al-Yaʿqūbī (d. around 300/913).

In the field of physics and technology the name of the Andalusian ʿAbbās b. Firmās (d. 274/887) shall be mentioned. Numerous physi-
cal and astronomical inventions are attributed to this versatile scholar. He gained lasting fame by an attempt to fly, which is said to have been successful over a certain distance.85

The development achieved in the other disciplines of science at that time was paralleled in historiography by the emergence of extensive, chronologically arranged histories of the world and of single realms. The best known and most significant surviving work of this genre is doubtless the Kitāb Aḥbār ar-rusul wa-l-mulūk by Muhammad b. Ǧārīr at-Ṭabarî (224/839-310/923).86 Arabist research has had access to this voluminous book since the commendable edition by M. J. de Goeje in 15 volumes (1879-98). However, the manner in which the sources are cited here meets with incomprehension and little sympathy among modern readers. The chains of transmission that accompany every account are not recognised as references to [19] written sources or authorized transmitters of books from earlier generations, but are considered as fictitious names of suppliers of oral information which had become accessible in whatever way. Thus not only an unjustifiably negative attitude towards the contents of these reports arises but the universal historiography also fails to realise the knowledge of the strict methods87 of citation of sources cultivated in the first centuries of Islam.

The development in the field of lexicography in this period is distinguished by a comprehensive treatment of single topics which subsequently contributed to the production of extensive alphabetically and thematically arranged dictionaries in the 4th/10th century. I would like to mention the book of plants (Kitāb an-Nabāt) by Abū Ḥanifa ad-Dinawarī88 (d. ca

87 A heavily abridged summary of this work entitled Kitāb al-Awān wa-l-buldān was edited by Ch. Pellat, al-Ǧāḥī ḥāl ṣī al-ǧāhrāṭyā al-insānīyā, in: al-Maʿārīq (Beirut) 60/1966/169-205.
282/895) as an interesting example of this genre. The surviving parts of this book, originally comprising 7 volumes, show clearly how far and how rapidly a branch of knowledge hitherto cultivated by the Greeks could already develop, in complete independence from the latter, amongst Arab philologists before the end of the 3rd/9th century. A study conducted exclusively on the basis of fragments of this book as cited in later dictionaries shows that Abū Ḥanīfa’s botanical descriptions are equal to those of the Materia medica by Dioscurides. According to Bruno Silberberg, the descriptions prepared by Dioscurides had a different motivation from those in the Kitāb an-Nabāt of Abū Ḥanīfa. The purpose of the former was to help the reader in the identification of herbs in the field, i.e. purely practical, while Abū Ḥanīfa’s presentation seems to have been inspired by a delight in the manifold varieties of plant morphology. In those days, Silberberg would still wonder: “How could the people of Islam reach in this respect the level of the brilliant Greeks or even surpass them at such an early period of their literature?”

Abū Ḥanīfa’s book bears witness to the use of a scientific botanical terminology; he “knows a lot of specialised expressions for the diverse features of plants which in an unbiased reader evokes the impression that they were part of a scientific nomenclature created for the sake of greater precision.” He displays an advanced scientific-morphological attitude, is familiar with the observation and description of physiological aspects and illustrates “complicated shapes in plants by comparison with familiar types.”

Amongst the examples of the development of sciences in this period, we may, lastly, mention the beginning of rhetoric (‘ilm al-bādi‘) and of poetics (‘ilm aš-ši‘r) towards the end of the 3rd/9th century. Although Aristotle’s works on these subjects were available in the Arab-Islamic culture area through translations, the original Arabic theory of literature seems to have been hardly influenced by it. The two works by Aristotle were, as part of the Organon, of interest merely to philosophers and logicians.

[20] The 4th/10th Century

In the 4th/10th century some Arabic astronomers asked whether the obliquity of the ecliptic was constant or subject to change. Ibrāhīm b. Sinān b. Tābit (d. 335/946) came to the conclusion that it was not constant. About fifty years later, Ḥāmid b. al-Ḥiḍr al-Ḥuḡandi convinced himself, after many years of observations in an observatory built for the specific purpose of finding the answer to this problem which featured a sextant with a radius of about 67 feet, that the obliquity of the ecliptic decreases continuously (infra vol. II, 25). The discussion of the question concerning the Earth’s rotation had already started towards the end of the 3rd/9th century—and apparently a heliocentric system had also been taken into consideration;

90 B. Silberberg, op. cit., p. 44 (reprint p. 164).
91 ibid, pp. 45-47 (reprint pp. 165-167).
92 ibid, p. 67 ff. (reprint p. 187 ff.).
93 ibid, pp. 65-66 (reprint pp. 185-186).
94 ibid, p. 69 (reprint p. 189).
towards the end of the century this idea found a convinced advocate in the person of Ahmad b. Muhammad as-Siğzi (infra vol. II, 16). Ga’far b. Muhammad b. Garir, a contemporary of as-Siğzi, also believed in the Earth’s rotation. Both scholars constructed astrolabes according to this view.  

At the same time, the fundamental work on fixed star astronomy was composed by ‘Abdarrahmân as-Šūfî in which he largely revised and updated the preliminary work by Hipparchus and Ptolemy (infra vol. II, 17).

In the field of astronomy we should also mention the remarkable invention of an instrument known by the name Ziğ as-safā’tâh, which Abû Ga’far Muhammad b. al-Hasain al-Hâzîn  

(1st half of the 4th/10th c.) constructed in order to be able to determine the longitudes of the planets directly by means of an instrument, without any arithmetical computations. We can trace the lasting effect of this instrument until the 16th century more clearly in Europe (where it was known under the name of equatory, v. infra vol. II, 173 ff.) than in the Islamic world.

Towards the end of the century an entirely new element widened the scope of astronomical observations, when the refraction of light by the atmosphere was taken into account and attempts were made to determine it quantitatively.  

In the field of mathematics great success was achieved in the 4th/10th century. Thus the already mentioned mathematician and astronomer Abû Ga’far al-Hâzîn was the first to succeed in solving an equation of the third order with the help of conic sections. Further progress in the extraction of cube roots was made in the second half of the century. Thanks to the work of H. Suter and P. Luckey, we know of two methods by the two mathematicians Kûşyâr b. Labbân and Abu l-Hasan an-Nasawi  

who were perhaps indebted to the established methods of the Chinese and Indians, but surpassed their predecessors. One of the two methods was the formula \( \sqrt[3]{a^2+b} = a + b/2a \) that can be derived from the binomial theorem for \( b < a \), which appears again in the first half of the 13th century in the work of Leonardo Pisano. The second is an approximation formula. As P. Luckey demonstrated, this is in fact the familiar Ruffini-Horner method of approximative solutions for algebraic equations.  

Muhammad b. al-Hasan al-Karağî, [21] one of the most eminent mathematicians of the time, already knew a formula for the fourth power. His contemporary Abu l-Wafâ’ Muhammad b. Muhammad al-Bûzağâni wrote a treatise on the extraction of roots up to and including the seventh power.  

Around the middle of the century, Ahmad b. Ibrahim al-Uqlidiî dealt with decimal fractions. According to his own statements, he was also the first to write on cubic numbers and cube roots.  

Another one of the great mathematicians of this period, who with their contributions defined the standard of the subject in the 4th/10th centu-
Continuing the work of his predecessors in the field of infinitesimal calculus, he calculated the volume of parabolic domes by a simple method. Among the contemporary attempts to find solutions for geometric problems leading to equations of the third order, Abu Sahl solved the problem of finding a segment of a sphere the volume of which equals that of a given segment and the surface of which equals that of another given segment. “He solves them with the help of an equilateral hyperbola and a parabola, whose points of intersection are used to measure the unknown quantity. He also includes a discussion of the precise conditions under which the problem can be solved.” Abu Sahl al-Kûhi also left us an elegant solution for the problem of trisecting an angle with the help of a hyperbola. In the course of his intense occupation with curves of the third degree, he invented the “perfect compass” (barkâr tâmm) for drawing conic sections. He also sought a geometrical answer to the physical-geometrical question of whether an infinite continuous motion was possible on a finite straight line.

His affirmative answer and the method used recall the approach by Giovanni Battista Benedetti (1530-1590). Maybe Abu Sahl intended, without saying so, to refute Aristotle, who had expressed the view that a continuous motion on a finite line was impossible.

The great achievements in mathematics of this period also include those in the field of plane and spherical trigonometry even though they are usually regarded as part of astronomy. The first systematic treatment of elements of trigonometry is to be found in the work of Abu l-Wafâ’ Muḥammad b. Muḥammad al-Bûzaġānî (328/940 - ca. 388/998). He treats the trigonometric functions uniformly and introduces a new method for the calculation of tables by a method of interpolation, with which [22] he calculates the tables of sines, tangents and cotangents. His sine table has an interval of 15 minutes. Abu l-Wafâ’, at the same time as his contemporaries Hâmid b. Ḥiḍr al-Ḥuğandi and Abu Naṣr Maṣṭûr b. ‘Ali Ibn ‘Irâq, claims priority in the discovery of the fundamental law of spherical trigonometry (infra vol. III, 133 ff.). This has primarily to do with the determination of the sides of a spherical triangle from its angles. It appears that Abu l-Wafâ’ really has the priority here. Moreover, he was also the first mathematician to attempt a solution of geometric problems with a pair of dividers of fixed gauge.

In the field of medicine, it should be emphasized that the level reached in this area led to the almost simultaneous yet independent publication of the first handbooks covering the entire
field of medicine in world literature. These are the Kāmil as-sinā'a at-tibbiyya by ‘Ali b. al-
‘Abbās al-Maḡūsī,\(^{122}\) at-Taṣrīf li-man ʿağiza ‘an at-ta’līf by Abu l-Qāsim Ḥalaf b. ‘Abbās az-
Zahrāwī\(^{122}\) and al-Muʿālaqāt al-Buqrāṭiyya by Abu l-Ḥasan Ahmad b. Muhammad at-Tabari.\(^{122}\) In
the eleventh century, the book written by ‘Ali b. al-‘Abbās al-Maḡūsī was translated into Latin as Liber pantegni by Constantinus Afri-
canus in Salerno and circulated in Europe for centuries under the authorship of the translator. In the year 1127, it appeared once more in a translation by Stephanus of Antioch.\(^{123}\) The 30th chapter of the at-Taṣrīf by az-Zahrāwī, devoted to surgery was translated into Latin by Gerard of Cremona in the 12th century. Its 28th chapter, dealing with materia medica, and the 30th about surgery belonged to the most widely circulated books of Arabic medicine in Europe. The third title, al-Muʿālaqāt al-Buqrāṭiyya, did not reach Europe before modern times.

Amongst the most important achievements of this century should also be counted the book Maṣāliḥ al-ābdān wa-l-anfūs by Abū Zaid Ahmad b. Sahl al-Balḥī\(^{124}\) (d. 322/934) in whom we encounter an early exponent of psychosomatics.\(^{125}\) One of the great advances in


\(^{125}\) The two extant manuscripts of his book were brought out separately in facsimile by the Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt 1984 and 1998; on this Zahide Özkan, Die Psychosomatik bei Abü Zaid al-Balḥī (gest. 934 A.D.), Frankfurt 1990 (re-print: Islamic Medicine, vol. 98).

\(^{126}\) Geschichte der Augenheilkunde im Mittelalter, op.
cit., p. 54.

he had discovered the first manuscript of al-Maqlisi’s book (infra vol. III, 3f.) in India and studied it.

Amongst the most significant achievements of the century were also two fundamental works on the history of science. One of them is the “Catalogue” (Fihrist) by Muhammad b. Abi Ya’qub Ishâq Ibn an-Nadim125 (d. ca. 400/1010) which, under its modest title, aims to list the scientific literature of all known culture areas. Such a work on the history of science—that astonishes us with its capacity to survey the material on a broad scope and to deal with foreign cultures objectively—would be inconceivable without an older tradition that made its appearance possible. We are reasonably familiar with this tradition today.126 We might also think, for instance, of the works by the widely-travelled encyclopaedist ‘Ali b. al-Ḥusain al-Mas‘ûdî127 (d. ca 345/956), which I see as an attempt to describe all known cultures and civilizations past and present.128 Ibn an-Nadim himself quite frequently offers interesting clues that help us understand how his book came about. In the second part of his 9th treatise on the cultures of India and China,129 he cites a passage about the religions and sects of India and their sacred places from a book written by an envoy whom the statesman Yahyâ b. Ḥâlid al-Barmaki (d. 190/805) had sent to India to report on its religions and to bring back medical drugs.

The second fundamental work of this period on the history of science was written in 377/987, the same year as Ibn an-Nadim wrote his book. It is the history of medicine (Ṭabaqât al-ḥātibbâ’ wa-l-hukamâ’) by the Andalusian physician Sulaimân b. Ḥassân Ibn Ḥulqîl130 which likewise is not restricted to the Islamic period. Comparing this work with the treatise written by Ishâq b. Ḥunain (d. 298/910) on the “History of Physicians” (Ta‘rîḥ al-ḥātibbâ’),131 which appeared half a century earlier and was based on a pamphlet by the Alexandrian Johannes Grammatikos (1st half of the 6th century CE), we may understand how far the historiography of science had advanced in this short period and the dimension of universality it had gained.

[24] I will have to pass over the development of humanities in the fields of philology, history, philosophy and the study of literature, to the details and importance of which Adam Mez devoted his Renaissance des Islâms,132 which appeared in 1922. I restrict myself to drawing the attention to one unique cultural-historic achievement of the 4th/10th century, namely the “Book of Songs” (Kitâb al-Ağânî) in twenty-four volumes by Abu l-Farâgh Ahmad b. al-Ḥusain al-Īsfahâni133 (d. 356/967). It is the extension and supplement of a collection of one hundred selected song compositions compiled by three famous musicians upon commission by Caliph Hârûn ar-Râshîd which was subsequently revised and augmented134 by the great musician and writer Ishâq b. Îbrâhîm al-Mauṣîlî135 (b. 150/767, d. 235/850). The monumental work by Abu l-Farâgh al-Īsfahâni follows the tradition of his predecessors whose works it eclipsed and in the course of time caused to fall into oblivion. It provides not only information about the compositions136 of the court

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128 I have written on this in the section on anthropogeography of the Geschichte des arabischen Schrifttums, which is still in manuscript.
132 Mez died in 1917. The manuscript of his book, which he was not able to revise, was prepared for printing by Hermann Reckendorf and published in 1922 in Heidelberg.
134 v. ibid., vol. 1, p. 371.
135 v. ibid., vol. 1, p. 378.
136 v. Henry George Farmer, The Song Captions in the
musicians, about their lives and the peculiarities of their music in theory and in practice, but also on the lyrics and their poets; beyond this, it mirrors the court life of the Umayyads and Abbasids and the intellectual circles that took part in it. The reader encounters here the cultivated life of an urbane society in whose intellectual interests priority is given to music, poetry and belles lettres. It is a book the like of which is not found in any other culture.

The accomplishments of this century also included the creation of compound ink by the addition of soot–inspired by Chinese ink–to the traditional ink made of iron-gallic, which consisted of vitriol, extract of gallnut, gum arabic and water.  

The 5th/11th Century

During the 5th/11th century, the issue of eccentric or concentric planetary orbits that had first been brought up in the 4th/10th century developed into a critical discussion of the Ptolemaic model. The first attempts in this direction had already been made in the preceding century. Abū Ga’far Muhammad b. al-Husain al-Ḥazīn postulated a concentric model, rejecting the theory of eccentricity and epicycles which he replaced by the assumption of variations in each planetary orbit relative to the plane of the ecliptic. Towards the end of the 4th/10th century, Abū Naṣr b. ‘Irāq discussed the idea—proposed by his contemporaries—of elliptic planetary orbits with minute differences between the length of the two axes and the possibility of actual unsteadiness in the revolutions. He was, however, convinced of a constant and uniform motion and that the apparent irregularities and the observed variations in the diameter of the planetary orbits could be explained by eccentricity. He apparently did not deem it necessary to retain any epicyclic motions.

The discussion took a new turn through Abū ʿAli Ibn al-Haṭṭām (d. shortly after 432/1041). In his “Doubts on Ptolemy” he expresses his reservations by stating that Ptolemy, in his model for the explanation of planetary motion violated the fundamental principle of the uniformity of circular motion by introducing the equant, because the motion of the centre of the epicycles on the deferent cannot be uniform any more. Ibn al-Haṭṭām was convinced that Ptolemy had postulated this faulty model so that he would not have to give up his idea of the system of the planetary orbits and that he had introduced fictitious models with no basis in reality.

Ibn al-Haṭṭām’s criticism of Ptolemy had a lasting influence on the succeeding generations that can be traced up to Copernicus. On the other hand, Ibn al-Haṭṭām adopted the concept of the heavenly spheres as actual transparent structures from Ptolemy’s Ἵπποθέσεις and elaborated upon it in his Kitāb fi Ḥa‘at al-‘ālam. This was clearly a backward step in the history of astronomy. The concept of tangible spheres, which was criticised about a hundred years later by Muhammad b. ʿOmar al-Ḥaraqī (d. 533/1139), remained relevant for centuries up to Newton’s time. On the other hand, the planetary kinematics (infra

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141 I owe this information to Dr. Armin Schopen, who has been working on this subject matter for many years; see now his Tinten und Tuschen des arabisch-islamischen Mittelalters. Dokumentation – Analyse – Rekonstruktion, Göttingen, 2006, p. 61 ff.
142 v. F. Sezgin, op. cit., vol. 6, p. 189.
143 v. ibid., vol. 6, p. 243.
II, 9f.) that Ibn al-Haitham elaborated in this connection were of great importance. The polymath Abu r-Raihān Muḥammad b. Ahmad al-Bīrūnī (362/973-440/1048), a contemporary of Ibn al-Haitham, took it upon himself to produce, besides numerous monographs on individual topics, a fundamental work on astronomy in which the development of the discipline up to his own time was to be treated systematically. He called it al-Qānūn al-Masʿūdī after the dedicatee Masʿūd b. Mahmūd b. Ṣebūktīgīn who ruled from Ghazna. Al-Bīrūnī followed the Ptolemaic system to a large extent, yet he was aware that science had progressed in the course of time and that he himself was able to contribute something new to it. As an example of his achievements, his calculation of the distance of the apogee from the vernal equinox is mentioned. He determined the acceleration and deceleration of the motion in the perigee from the tables by Al-Bīrūnī himself had a strong inclination to this matter from his youth. His teachers had solved the problem of the apogee and supplied the book with a tangent table. Soon it occurred to him to use the new method also for the determination of longitudinal differences and distances between localities. The longitudinal differences calculated accordingly were of great importance.

One of the most significant achievements of the century was the expansion of mathematical geography into an independent discipline. Again it is al-Bīrūnī to whom this great credit goes. We learn from his work devoted to this topic, Tahdīd nihayāt al-amākin li-taṣḥīh masāfāt al-masākin, that during the 4th/10th century people in the eastern part of the Islamic world were fervently engaged in the determination of geographical coordinates. We hear that al-Bīrūnī himself had had a strong inclination to this matter from his youth. His teachers had solved the problem of the calculation of the sides of a spherical triangle from its angles, which later led al-Bīrūnī to devote a [26] special monograph to problems of spherical trigonometry. It is the extant Kitāb Maqālīd ‘ilm al-hai’a. Here the discipline is still subordinate to astronomy. In the eighth chapter of his al-Qānūn al-Masʿūdī, al-Bīrūnī discussed the functions of tangent and cotangent and supplied the book with a tangent table.

At the beginning of the 5th/11th century, both al-Bīrūnī and Ibn al-Haitham independently came to the conclusion that the traditional method of determining the meridian line by means of the Indian circle was unsatisfactory due to errors caused by variations in the sun’s declination. Ibn al-Haitham, unaware of the method proposed by al-Bīrūnī, found a way to determine the meridian by observing the corresponding altitudes of a fixed star and devised an instrument for this purpose (infra II, 146). Ibn al-Haitham’s

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method first appeared in Europe in the work of Regiomontanus of the first quarter of the 15th century.

The 5th/11th century also brought about great achievements in the field of mathematics. The works of al-Biruni and Ibn al-Haitham alone show that substantial progress compared to the preceding century was already made in the first 30 or 40 years of the century.

Besides the above-mentioned advances towards infinitesimal calculus, al-Biruni was able to enumerate in his Qanun, the fundamental work of astronomy, twelve methods for trisecting an angle worked out by his predecessors and contemporaries. These problems were solved through cubic equations and led also to attempts at solving the equations numerically. An interesting example for such an attempt was al-Biruni’s exercise to determine the sides of a nonagon. Of his numerous further achievements in the field of mathematics known today, we shall mention only his mensuration of the circle through the sides of an inscribed and circumscribed nonagon, which is actually a trigonometric problem; al-Biruni reduces it to a cubic equation or (alternatively) solves it by means of a special iteration process (istiqrā’).

Recent research has pointed out significant achievements by Ibn al-Haitham as well; some of these may be mentioned here. The famous mathematical-optical ‘problema Alhazeni’, which is named after him, occupies an important place in the history of mathematics. He posed that problem, i.e. “to determine the point of reflection of a spherical mirror from which the image of an object at a given place is reflected into an eye that is also at a given place” and solved it himself with an equation of the fourth order. An important further development of the problem posed and solved by Ibn al-Haitham is reflected in the Kitab al-Istikmal by al-Mu’taman.

Ibn al-Haitham is also one of the pioneers of infinitesimal calculus. Going beyond his predecessors Archimedes, Tâbit b. Qurra, Ibrahim b. Sinan b. Tahit and Abu Sahl al-Kühî, he also calculates paraboloids “which are produced by the rotation of the parabola around any arbitrary diameter of itself, and then especially those which are produced by the rotation of a part of the parabola around the ordinate.”


\(^{159}\) v. H. Suter, Die Abhandlung über die Ausmessung
solution, “in which the sum of the fourth power occurs, contains a calculation which equals the computation of the definite integral $\int_0^a f(t) \, dt$.\footnote{165}

One of the few achievements of Ibn al-Haïtam in the field of geometry known so far assures him an outstanding position in the history of the discussion of Euclid’s postulate of parallels (infra III, 126 f.). He attempts to prove the fifth postulate of the Elements according to the principle of motion, which leads to the assumption that lines of constant distance to a straight line must also be straight lines. Ibn al-Haïtam “here takes a course which later many of his direct or indirect followers, including the geometers of the 18th century, pursued.”\footnote{164}

[28] In trigonometry we may refer to his theorem on the spherical cotangent, which, interestingly enough, he derives purely geometrically and applies it in his treatise on the determination of the prayer direction (qibla). With this third main theorem of spherical trigonometry, Ibn al-Haïtam proves to be a precursor of François Viète (1593).\footnote{165}

We shall not forget a contemporary of Ibn al-Haïtam and al-Birûnî by the name of Muhammad b. al-Laït Abu l-Ġûd.\footnote{164} We know a construction of his of a heptagon inside a circle, which he reduces to an equation of the third order.\footnote{166} About half a century earlier this construction had already been accomplished by Abû Sahl al-Kûhî\footnote{166} and Ahmad b. Muhammad as-Sîzî,\footnote{167} but Abu l-Ġûd took another path\footnote{166} and found the construction of the equation $x^3 + 13\frac{1}{2}x + 5 = 10x^2$ which his predecessors did not succeed in finding.\footnote{166} In the construction of the heptagon the influence of the Arabic-Islamic culture area on European mathematicians is noticeable well into the 17th century.\footnote{170}

Abu l-Ġûd was apparently the first mathematician who dedicated a treatise to forms of equations of the third order and methods for their solution. We learn this from his successor ‘Umar al-Ḥaiyâm (2nd half of 5th/11th c.), who himself had not seen the work but had been informed about it by a contemporary.\footnote{171} The surviving work on algebra by ‘Umar al-Ḥaiyâm (al-Barâînī, ‘alâ masâ’il al-ḡabr wa-l-muqâbala) was edited, studied and translated into French by Franz Woepcke 150 years ago and can be considered the true reflection of the development which algebra underwent in Arabic-Islamic mathematics. Al-Ḥaiyâm enumerates twenty-five types of

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\footnote{166} ibid, vol. 5, p. 353.

equations of which twelve are of linear or quadratic type; the rest consists of equations of the third order which can be solved by conic sections and are treated systematically by him. He complains that no algebraic solution of those equations had yet been found, but expresses his hopes that future generations might perhaps succeed in this.\textsuperscript{167} Al-Ḥaiyām also points out that cubic equations which cannot be reduced to quadratic ones can generally not be solved with compass and ruler, i.e. through the properties of the circle. This view was later also expressed by René Descartes (1637) but was only proven by Pierre Laurent Wantzel (1837).\textsuperscript{173}

The fact that the “excellent book” by ʿUmar al-Ḥaiyām had remained unknown “until the most recent times” and that mathematicians like Fermat (around 1637), Descartes (1637), van Schooten (1659), E. Halley (1687) and others had “had to invent similar constructions over again” was regretted by the mathematician-historian Johannes Tropfke as late as 1937.\textsuperscript{174}

Al-Ḥaiyām, who also counts among the great Persian poets and is a highly esteemed authority in other areas of science like astronomy and physics, found his own solution for the postulate of parallels. He rejects the use of motion as a means of proof in geometry, which Ibn al-Haitham had supported. His solution reappears in the 18th century in the work of the Italian mathematician Girolamo Saccheri (infra III, 127 f.). In the 5th/11th century we encounter several decisive achievements in the field of physics, including optics and meteorology.\textsuperscript{175} Despite admirable individual studies by Eilhard Wiedemann and his disciples and despite the excellent work by Matthias Schramm, Ibn al-Haitham’s Weg zur Physik (1963), the discipline of physics belongs to those areas of Arabic-Islamic science which still await a comprehensive treatment of however modest a scope. Approaching Ibn al-Haitham from his main work on optics (Kitāb al-Manāẓir) and his astrophysical writings, Schramm came to the conclusion that in these works Aristotelian physics, applied mathematics, traditional astronomy and optics are combined, and that this can be considered as typical of Ibn al-Haitham’s scientific research.\textsuperscript{176} On the other hand, he succeeded, according to Schramm, “in transforming Aristotelian metaphysics of nature, with the study of which he began his scientific endeavours, into a physical theory that provides a dynamic explanation of the kinematic model postulated by Ptolemy.”\textsuperscript{177} With his efforts in this respect, Ibn al-Haitham had “taken the first step that was to lead to one of the most remarkable achievements of the human mind as such, from the metaphysics of nature and its mathematical description towards physics, towards exact natural science based on mathematical methods.”\textsuperscript{178}

Ibn al-Haitham’s continuously expanding physical-astronomical knowledge resulted in numerous monographs,\textsuperscript{179} such as on the shape of the Earth, on burning mirrors, on rainbow and halo, on moonlight, on the light of the stars, on the anatomy of the visual organ and the nature of visual perception, on the “image of the eclipse” and on the lunar spots. He put down his knowledge of optical matters in the above-mentioned comprehensive work Kitāb al-Manāẓir. Like his Arabic predecessors Abū Bakr ar-Rāzī (d. 313/925), al-Fārābī (d. 339/950) and his contemporary Ibn Sinā (d. 428/1037), and opposing Euclid and Ptolemy, he supported the Aristotelian view according to which visual perception does not involve rays emanating from the eye but rays emanating from the object. Mathematics and experiment always remain

\textsuperscript{167} ʿUmar al-Ḥaiyām, op. cit., p. (Arabic) 6, tr. p. 9 (reprint op. cit., pp. 33, 199); F. Sezgin, op. cit., vol. 5, p. 50.


\textsuperscript{174} J. Tropfke, op. cit., vol. 3, p. 133.

\textsuperscript{175} On this see F. Sezgin, op. cit., vol. 7, pp. 203-305.


\textsuperscript{177} ibid, p. 143.

\textsuperscript{178} ibid, p. 145.

\textsuperscript{179} ibid, pp. 274-284.
in the foreground with all the problems he addressed, not only in the case of visual perception. According to Schramm’s opinion, the “Optics” display the mathematical genius of their author. For experimental purposes, Ibn al-Hai˚am constructed several instruments and devices, including a camera obscura.

[30] In 1890 Leopold Schnaase gave an excellent evaluation of Ibn al-Haitam’s “Optics” and its significance, on the basis of its Latin translation. This evaluation was corroborated in a masterly way by Schramm’s study. Referring to Ibn al-Hai˚am with the Latinized form of his name, Schnaase writes: “A comparison of Alhazen’s achievements with those of Ptolemy shows what remarkable progress optics owe especially to the former; Alhazen was the first physicist to take into account the anatomy of the eye and to develop, on that basis, an elaborate theory of vision, a theory which—in spite of incorrect premises on the functions of the crystal lens—achieved results that almost agree with modern findings. The assumptions and experiments by which he determines the conditions of seeing single and double images must be regarded as his discoveries. Furthermore, he was the first to find definite proof that the theory of visual rays is incorrect, thus removing this theory once and for all from physics and establishing its opposite—a shift in the fundamentals of optics which was of far-reaching consequence. Even the claim that the transmission of light takes a certain time was already made by him. What a tremendous gap separates Ptolemy and Alhazen, the Greek and the Arabic school in this regard.”

“… Even if views similar to his had occasionally been voiced earlier, to have clarified and to have decided finally between opposing views goes undoubtedly to Alhazen’s credit; and thus he caused the magnificent shift in the fundamental theories of optics through which, at the beginning of the new millennium, new prospects were opened up for research and preparations were made for the dazzling discoveries of the modern age.”

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[31] To this highly informative judgment by a physicist of humanistic persuasion from the end of the 19th century, I add the opinion of the contemporary historian of medicine, H. Schipperges, which he formed by reading Matthias Schramm’s study on the role of Ibn al-Haitham in the history of physics. He agrees with Schramm “that it was indeed Ibn al-Haitham who introduced for the first time a new methodic character into the natural sciences, a methodology which clearly distinguishes him from the Greek approach and which, passing beyond the epoch of Galileo, links up with modern experimental physics”.

From the surviving works and also the titles of the lost treatises by Abu r-Raiihan al-Biruni we can appreciate the original and important contribution made to the physical science of this period. The maturity with which problems of natural sciences were approached during that period is reflected in the correspondence between al-Biruni and Abu ’Ali Ibn Sinâ, who was eleven years his junior, i.e. seventeen at the time. Besides the surviving texts of this correspondence, Al-Biruni’s own statements on the question of the speed of light and global warming in his “Chronology of Eastern People” (al-Á‘târ al-bâqiya ‘an al-qurûn al-ḥâliya), where he refers to this correspondence and speaks of Ibn Sinâ as a young man of merit, are vivid illustrations of the elevated scientific spirit of that period. An assessment of al-Biruni’s status in the history of physics is still awaited. So far, mainly his achievement in determining the weights of objects having the same volume has been studied and evaluated from the perspective of the history of science. After several failed experimental setups, he finally succeeded in constructing a device for this purpose which resembles the modern pharmacy-pycnometer (infra V, 9 ff.). The specific gravities of various metals and precious stones as determined by him and his successors with this device are almost identical to their modern values. Mention should also be made of the interesting attempt to determine the height of the atmosphere in the second half of the 5th/11th century. The problem was solved by trigonometric-astronomical methods; this solution can be found in the Latin translation De crepusculis et nubium ascensionibus, which was erroneously attributed to Ibn al-Haitham. The real author was the Andalusian scholar Abû ‘Abdallâh Muhammad Ibn Mu‘âd al-Ğaiyâni. This Latin treatise, printed in Portugal in 1542, had a lasting impact on the Occident.

[32] The two major works by Abû ‘Ali Ibn Sinâ (d. 428/1037), his “Canon of Medicine” (al-Qânûn fi t-ţibb) and the encyclopaedia of philosophical and exact sciences entitled “Book of Healing [of the Soul]” (Kitâb aš-Śifâ‘), be-

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long indisputably to the most important scientific achievements of the Arabic-Islamic culture area.

Julius Hirschberg\textsuperscript{99} described the “Canon” by this extraordinarily talented and diligent thinker as “distinguished by order and exactitude, a very extensive and comprehensive didactic system covering the entire science of medicine including surgery—almost without parallel in world literature.” He goes on to add: “From the Greeks we have inherited only collections, extracts, compilations. The Canon is a work as of one mold. Nowadays a complete medical staff is required to produce a ‘manual’ like this. For half a millennium, the Canon remained effective and Ibn Sinä reigned supreme, like Aristotle and Galen.” The Canon was translated into Latin in the 12th century and influenced medical science in the West up to the 17th century.

The second, equally extensive, encyclopaedic work by Ibn Sinä deals with the theory of the principles of the natural bodies and the cosmos, origin and end, potency and suffering in nature; it covers meteorology and geology, psychology, botany and zoology, mathematics and astronomy, music, philosophy and logic.\textsuperscript{99} The book was translated into Latin by John Hispaniensis in the 12th century and influenced medical science in the Occident for centuries.

In the context of Ibn Sinä’s two works we should also mention the great achievements of the Christian ophthalmologist ‘Ali b. ‘Isä al-Kahhäl (1st half of the 5th/11th c.). J. Hirschberg considers his work as leading amongst the textbooks of ophthalmology produced for the next 800 years. About its Latin translation, however, he wrote: “Ophthalmology in the Occident would have reached a higher standard and could have contributed more to the benefit of humanity had the early Latin translation of his work been more reliable and consequently in wider circulation.”\textsuperscript{992} Hirschberg points out that operations under anaesthesia belonged to the common medical procedures and regrets that surgically induced “sleep” (\textit{tanwîm}) practised by the Arabs remained completely unknown to the historians of medicine.\textsuperscript{995}

From the geographical works of this century the first comprehensive geographical lexicon known to us should be mentioned. It was compiled by Abû ‘Ubâd ‘Abdallâh b. ‘Abdâl‘azîz al-Bâkri\textsuperscript{104} of Cordova (d. 487/1094). This geographer, historian and lexicographer compiled an alphabetically arranged reference book on the basis of numerous monographs and other available sources about caravanserais, mountains, rivers, wells, etc. The same author left behind a valuable topographic geography (\textit{Kitâb al-Masâlik wa-l-mamâlik}), independent of the eastern school of anthropogeography. Its high value lies in its excellent description of Spain and rare information on Central and Eastern Europe and North Africa, taken from sources otherwise lost.\textsuperscript{995}

In the field of historiography we shall mention al-Birûnî’s book on India, which bears witness to its author’s exemplary veracity, critical mind, keen observation and a remarkable cosmopolitan openness and objectivity. Al-Birûnî deals with the culture, religions and sciences of the Indians on the basis of his own research and observations made over many years while living


\textsuperscript{993} ibid, p. XXXVI; F. Sezgin, op. cit., vol. 3, p. 338.

\textsuperscript{994} Mu‘gâm ma sta‘gâm min asmâ‘ al-bilād wa-l-mawâdî, ed. Muṣṭafâ as-Saqqa‘, 4 vols., Cairo 1945-1951.

in India. In the introduction, he states: “This is not a polemical book but a plain factual report. I shall describe the theories of the Hindus as they are and in that connection mention similar theories of the Greeks in order to demonstrate the relationship between the two.” Al-Birūnī’s book appears to stand in the tradition of the spirit we already encounter in the early Abbasid period (supra, p. 23) and which aims at getting to know foreign cultures and religions, a spirit that found expression in many travelogues, in the masterworks of al-Mas‘ūdī (supra, p. 23), and in al-Birūnī’s “Chronology of Eastern People”. Al-Birūnī’s book on India marks an apex that—perhaps not only in Arabic-Islamic culture—could not be surpassed.

In conclusion of this selection of outstanding achievements of the 5th/11th century we shall mention the two extremely important works by ‘Abdalqāhir b. ‘Abdarrāḥmān al-ʿGūrānī (d. 471/1078) from the field of linguistics. These are his Kitāb Dalā’il al-ʾi‘rāz and the Kitāb Asrār al-balāgha. In an excellent study of the former work, Max Weisweiler pointed out that its author attempts “to understand linguistic phenomena psychologically according to their cause, purpose and effect.” Al-ʿGūrānī does not seem to have been aware that with his conceptions and examples he had created a stylistic grammar. In the next generation it already turned into a new branch of linguistics in the form of a systematically arranged textbook entitled ʿilm al-maʿānī. That Al-ʿGūrānī’s admirable ideas could not appear all of a sudden, but represent an already high standard achieved in the course of a long-term upward development requires, it is hoped, no further explanation. The achievements preceding al-ʿGūrānī are also quite well known today.

While editing and translating ‘Abdalqāhir b. ‘Abdarrāḥmān al-ʿGūrānī’s second book entitled Asrār al-balāgha (“The Secrets of Style”), Hellmut Ritter discovered “a psychological foundation of aesthetic judgments on poetry.” This scholar, who spent some twenty-five years editing the book and translating it into German and who was undoubtedly one of the greatest connoisseurs of Arabic language and literature, stressed the fact that to his knowledge something like that had “never before been attempted on Islamic [34] ground.” At any rate, al-ʿGūrānī in retrospect turns out a precursor of ʿilm al-bayān which expanded, three to four generations later, into an independent branch of linguistics.

The 6th/12th Century

Returning to astronomy, we see that Ibrāhim b. Yaḥyā az-Zarqālī, active around the turn of the 5th/11th to the 6th/12th century in Muslim Spain, achieved a significantly more exact measurement of the proper motion of the Sun’s apogee than his predecessors. He arrived at a value of 1° in 299 years for this motion, i.e. 12.09" in one year, which approaches the current value of 11.46" very closely. This value and knowledge of the model developed in this connection by az-Zarqālī reached Copernicus via two compilations, Theoricae planetarum by Georg Peurbach and Epitome by Johannes

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Regiomontanus. By means of comparison it has already been established that the tables used by az-Zarqālī while formulating his solar theory and the corresponding tables found in De revolutionibus by Copernicus show general agreement in arrangement and organisation, leaving aside one minor deviation. Johannes Kepler also learned of az-Zarqālī’s observations for determining the Sun’s apogee. Furthermore, it is assumed that there might be a connection between Kepler’s concept of the Mars-orbit as an oval and az-Zarqālī’s oval orbit of Mercury.

A groundbreaking invention in the history of the astrolabe also bears az-Zarqālī’s name. He replaced polar stereographic projection with horizontal projection, whereby the main body of the instrument was reduced to one single plate rather than appending separate plates for various geographical latitudes. This instrument, known in astronomical literature as saphæa or universal disc, later enjoyed wide circulation in Europe (infra II, 116 ff.).

Another astronomical instrument that appeared in the 6th/12th century found wide dissemination in Europe under the name torquetum. It was developed by the Andalusian astronomer Ǧābir b. Aflāḥ (infra II, 154). He described the instrument in his work on the revision of the Almagest in which he criticises Ptolemy sharply. It is well-known that this criticism of the Almagest, which was translated into Latin by Gerard of Cremona, a contemporary of the author, exerted considerable influence both on the subject itself and on mathematics (infra II, 12).

The linear astrolabe of Šarafaddin al-Muẓaffar b. Muḥammad b. al-Muẓaffar Ǧaṭ-Tūsī (d. after 606/1209) is yet another astronomical instrument invented at this time. In this instrument, called ‘aṣā at-Ţūsī (“at-Ţūsī’s staff”) after its inventor, the projection of a planispheric astrolabe is transcribed on a straight line drawn on a staff (infra II, 134 ff.).

Meanwhile in theoretical astronomy, strong opposition against the Ptolemaic system of celestial motions arose in the 6th/12th century in Muslim Andalusia. The exponents of this criticism were mostly philosophers, namely Muhammad b.Yahyā Ibn Bāggā (d. 533/1139), Muhammad b. ʿAbdalmalik Ibn Ṭufail [35] (d.581/1185), Muhammad b. Ahmad Ibn Rušd (d. 595/1198) and Ibn Ṭufail’s pupil, Nūraddin al-Bitrūǧī (ca. 600/1200). They found the principle of uniformity in planetary motions disturbed by the concept of eccentricity and epicycles and attempted to restore this basic principle by means of new models. The book of the last representative of this school of thought, Nūraddin al-Bitrūǧī, exercised a great and lasting influence on western astronomy. Shortly after the book had first appeared it already reached European countries beyond Spain in translation by Michael Scotus (d. ca. 1235). Like Ibn Ṭufail and Ibn Rušd, al-Bitrūǧī was convinced that the planetary orbits must run concentrically around the centre of the Earth and, like Ibn Rušd, he believed that they follow a spiral path around various axes (infra II, 12 f.).

In the eastern part of the Islamic world, the above-mentioned Šarafaddin at-Ţūsī (d. after 606/1209) played a pivotal role in the mathematics of this epoch. With his book entitled al-Mu’ādalāt, he had an important part in the process of the systematic treatment of equations of the third order. He pursued ‘Umar al-Ḥāiyām’s path, and his book gives an idea of the progress achieved in the mathematics of the Islamic world during the preceding century. This progress is apparent primarily in the fusion of arithmetical and geometrical traditions and the

203 v. F. Sezgin, op. cit., vol. 6, p. 43.
204 v. ibid, vol. 6, p. 43.
205 v. ibid, vol. 6, pp. 43-44.
206 v. ibid, vol. 6, p. 44.
207 v. ibid, vol. 6, pp.45, 93.
208 v. F. Sezgin, op. cit., vol. 6, pp. 36-37
formulation and proof of a number of algebraic processes. 210

From the western part of the Islamic world, I would like to mention once more the name of the Andalusian mathematician and astronomer Ǧābir b. ʿAflaḥ. Many historians of mathematics are of the opinion that the trigonometric chapter of his critical review of the Almagest exerted considerable influence on this discipline in the West. Thus Regiomontanus (1436–1476) in his De triangulis omnimodis is said to have used material from Ǧābir b. ʿAflaḥ’s book. Whereas in the first books of this work, to quote Johannes Tropfke, 211 “he independently revised the results of his predecessors, in the fourth book he adopted Ǧābir’s proofs almost verbatim.” In the history of spherical trigonometry 212 one basic formula is called “Geber’s theorem” after him. It states that a right-angled spherical triangle can be calculated from a given side α and a given adjacent angle β, which leads to the formula $\cos \alpha = \cos \alpha \sin \beta$.

Concluding the description of mathematics of the 6th/12th century, a mathematician of the first order, Ahmad b. Muḥammad Ibn as-Sarî b. ʿaš-Ṣalâh (d. 548/1153), shall be mentioned. He wrote a number of discourses devoted to the verification and criticism of the results of Greek and earlier Arab authorities. From a study by Matthias Schramm on one of those discourses, we learn that Ibn ʿaš-Ṣalâh was actually qualified for such a criticism and that his aim was historical justice; for instance, when reviewing the criticism of his Arab predecessors on the Greeks, he sometimes refutes the former. 213

[36] From the field of physics and technology we know at the present time at least two important works which document the high standard of those disciplines in the 6th/12th century in the Arabic-Islamic culture area. They are Mizān al-hikma by ʿAbdarrahmān al-Ḥāzīnī 214 (written 515/1121) and al-Ǧāmiʿ bain al-ʿilm wa-l-ʿamal fī ʿināʿat al-ḥiyāt by Abu l-ʿIzz Ismāʿīl Ibn ar-Razzāz al-Ǧazāri 215 (written around 600/1203).

The title Mizān al-hikma promises a book about the “balance of wisdom”, but the content of the book goes far beyond that. Above all, the author extends and supplements al-Birūnī’s results on the determination of specific gravities. The balance mentioned in the title is constructed in such a way that it can achieve a precision of 1/60000 (infra V, 5f). Al-Ḥāzīnī has a clear notion of the dependence of the specific gravity of water on temperature and interprets in this sense his observation that water put on his balance had a lower weight in summer than in winter. He also describes a special clepsydra built on


215 The work, preserved in several manuscripts, was edited by Ahmad Y. al-Hasan, Aleppo 1979; Engl. transl. Donald Hill, The Book of Knowledge of Ingenious Mechanical Devices, Dordrecht and Boston 1974; facsimile edition of the manuscript, Ayasofya 3606, by Institut für Geschichte der Arabisch-Islamischen Wissenschaften 2002.
the principle of a balance with which minutes were measured (infra III, 117), and also an ar-eometer, which had already been known in late antiquity (infra V, 12 ff.), for the determination of the specific gravity of liquids.

Of great interest is al-Hâzînî’s knowledge that a body gains weight in thinner air and loses weight in denser air or when submerged in water. The following idea of his is also remarkable: “Liquids occupy a larger volume in a container when the latter is closer to the centre of the Earth and a smaller volume when the container is farther removed from it.” In 1890 E. Wiedemann found the same idea in Roger Bacon’s *Opus majus* and observed that the proofs of both authors are related, even if Bacon’s reasoning is “somewhat more laboured than the Arab’s”.

Al-Hâzînî’s *Mizân al-hikma* is a book of physics in the strict sense of the word; it imparts to us a wealth of physical laws known to Arabic-Islamic scholars in the 6th/12th century. The high quality of the description of the experiments reminiscent of Ibn al-Haiṭam’s and al-Bīrûnî’s time is remarkable, and also the fact that he uses the experiment as a systematic means for research.

[37] The second of the books mentioned was written by the otherwise unknown Ibn ar-Razzâz al-Ğazari upon commission by the local ruler of Āmid Nâširaddin Mahmûd b. Muhammad b. Qarâ’arštân (r. 597/1200-619/1222), and was completed two years after the latter’s accession to power. Several manuscripts of the book with illustrations in colour have come down to us. It is without doubt the most beautiful of the extant works in the field of mechanics. The author mentions amongst the contents of his book “water driven machines for equinoctial and temporal hours” and devices used for “moving bodies from their natural position by means of [other] bodies”. He describes fifty machines and devices in all clarity from the point of view of an engineer and provides them with fifty complete and about a hundred partial drawings of such quality that one can reconstruct the machines without any substantial problems.

This book, originating in the eastern part of Asia Minor under the adverse political conditions of those times when the war against the crusaders impeded communication amongst the people and the exchange of books and knowledge between the countries of the Islamic world, probably does not reflect the state-of-the-art reached by Arabic-Islamic technology at that time or even in general. It is a book compiled by a capable engineer according to his talents and his understanding on the basis of his knowledge of the sources and within the bounds of the conditions of his environment. For instance, when the conical valve for regulating the water level in hydraulic devices appears for the first time in al-Ğazari’s book, this is no sufficient reason to consider him its inventor. Incidentally, this type of valve was not known in Europe until the 18th century. Whether it reached the West from the Arabic-Islamic area or whether it developed

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269 v. the introduction to our facsimile edition, p. VIII.
again independently remains a matter of speculation.\textsuperscript{220}

As far as al-Gazari’s own creative contribution to his book is concerned, we can only assume—as long as the research in the history of technology in Arabic-Islamic culture does not yet stand on firm ground and its position in the universal history of science has not yet been sufficiently cleared up—that some of the inventions described in his book are his own.\textsuperscript{221} At any rate, it is an historic document of high cultural and scientific standards, so much can be said with certainty. It provides unique material on technical instruments and devices, about their construction and the materials used. Thus the book contributes fundamentally to the understanding of the general history of technology, although it is possibly not representative of the standard attained in the Islamic world in general. Some of the machines described show affinity to such which later appear in European books on mechanical devices and automata, even though there does not seem to be a direct connection.

The most important achievement of the 6th/12th century in the field of geography is the work by Abū ‘Abdallāh Muḥammad b. Muḥammad b. ‘Abdallāh al-Idrīsī, a descendant of Idrīs II who ruled in Malaga during the years 1042-47 and 1054-55 CE. This nobleman from the western part of the Islamic world came to Palermo either as a traveller or as a guest of the Norman king Roger II (r. 1130-1154). There he prepared, during his stay of many years, upon commission by his host, a circular world map on \[38\] a silver disc, 70 regional maps and a book entitled \textit{Nuzhat al-muštāq fi Ĥtirāq al-āţāq} on the geography of the world. For the succeeding king, Guillaume I (r. 1154-1166) he abridged his book under the title \textit{Uns al-muhaq wa-rauḍ al-firaq} with 72 regional maps. In the year 1160 CE, the circular silver world map (Tabula Rogeriana) was smashed to pieces by rebels and divided amongst themselves.

The world map and some of the sectional maps survive as the final product of multiple copying in a number of manuscripts of the geographical work. The question of how al-Idrīsī was able to create these maps, and the question of the importance of the entire work for the history of geography, were discussed for a long time and found widely differing answers. In the discussion of the map it was almost always assumed that al-Idrīsī must have used the Ptolemaic world map as his model. The world map and several regional maps by the geographers of Caliph al-Ma’mūn (r. 198/813-218/833) could of course not be taken into account, as they were rediscovered only about twenty years ago. While referring to the detailed discussion of this question in volumes 10 and 11 of my \textit{Geschichte des arabischen Schrifttums} and to the yet unpublished manuscript of the volume on anthropogeography, I will state my view very briefly here: The Ptolemaic Geography itself actually consists of an instruction for drawing maps and as such most probably did not include any maps. The maps attributed to Ptolemy were reconstructed around the turn of the 13th to the 14th century CE by the Byzantine Maximos Planudes on the basis of the coordinates from Ptolemy’s book and probably by consulting the world map of the Ma’mūn geographers.\textsuperscript{222} Today we have evidence that al-Idrīsī used the Ma’mūn map as his model. Leaving aside certain obvious errors and deviations, such as the omission of the graticule which was erroneously replaced by lines of equal distance meant to represent the seven climates, the Idrīsī map surpasses its model in various respects. Thus Europe, in particular the Mediterranean area, is represented more accurately, North-East Asia has been completely revised, and Central Asia with its systems of


\textsuperscript{221} V. the introduction to our facsimile edition, p. VIII-IX.

\textsuperscript{222} V. F. Sezgin, op. cit., vol. 10, pp. 50 - 57.
lakes and rivers also has been developed further. Hence the question arises how a geographer in Sicily in those days could have accomplished this cartographic survey, which in fact required work to be carried out locally and for generations. In fact, I believe that the results of such work reached al-Idrisi in the form of a book supplied with maps. The work written by one Ḥanāḥ (Gağān or Ġanāḥ) b. Ḥaqqān al-Kimāki is mentioned by al-Idrisi amongst his sources. Apparently, this geographical-cartographical work by a prince of the Kimak-Turks was based on a long-term collection of data, gathered locally in the tradition of Arabic-Islamic cartography. The shape of North and North-East Asia in al-Idrisi’s map, which is completely new compared with the map of the Ma’mūn geographers—not to mention the so-called Ptolemaic maps—appears in most western world maps until the 18th century. As far as I am aware, no historian of geography has as yet asked himself from where this depiction of Asia in those Western maps originated.

In my opinion, al-Idrisi’s world map, despite its shortcomings, allows us to trace the development of cartography since the appearance of the Ma’mūnian map in the Arabic-Islamic culture area [39] and, furthermore, it helps us find an answer to the old question concerning the origin of the so-called portolan-maps and their “sudden emergence” amongst European navigators and cartographers at the turn of the 13th to the 14th century.

However, this high estimation of al-Idrisi’s world map from the viewpoint of the history of cartography presupposes the clarification of one fact. The circular world map which survived in several manuscripts of his Geography and which had suffered from repeated copying was known only to a few arabists prior to the appearance of the commendable work Mappae arabicae224 (1926-1931) by Konrad Miller. In his book Miller published the surviving copies of the circular world map, the sectional maps and a world map reconstructed by him after the sectional maps. In spite of al-Idrisi referring to his world map as being circular and although its copies as preserved in various manuscripts are, indeed, all circular, Miller was convinced that the world map must have been rectangular (infra III, 28) and consequently felt justified in reconstructing the missing original by patching together the seventy rectangular sectional maps. The orthogonal world map thus reconstructed found wide distribution, even though not only is the north depicted as wide as the regions of the equator, which distorts the cartographic image, but also the configuration of northern Asia and Africa is obscured completely. Only a few people would be aware that this map was reconstructed by Miller using al-Idrisi’s sectional maps, while the world map found in al-Idrisi’s book itself is circular and substantially different from the one in circulation. With the aid of electronic data-processing, we have attempted to graduate the sectional maps orthogonally and to transform them into a stereographic projection, occasionally making reference to the extant circular world map. We believe that the resulting map gives a better idea of al-Idrisi’s intentions and hence published it as a poster.

As regards the text of al-Idrisi’s book, we can say that through his Arabic sources we gain much information about the geography of European countries. The parts concerning Sicily, Italy, France, Germany, the Scandinavian and Slavonic countries and the Balkans have consequently been made the subject of detailed studies by arabists.225


225 Most of these studies were collected at the Institut
Meanwhile, in the field of philosophy a new school of thought developed, known as falsafat al-išrāq. Its founder was Śīḥāb al-Dīn Yaḥyā b. Ḥabas as-Suhrawardī (d. 578/1181). The basis of his new philosophical system was a metaphysic of light. “Being and non-being, substance and accident, cause and result, thought and feeling, soul and body, he explains all through his doctrine of Ishrāq; he regards everything that lives or moves exists as light and even his proof for the existence of God is based on this symbol.”

In the area of philology an increasing interest in terminologies and foreign languages, and in the investigation of foreign elements in Arabic, is apparent in this century—a trend not without precursors in the preceding centuries. As an example we may refer to the botany by the above-mentioned al-Idrīsī, his al-Ǧāmi‘ li-sīfāt aṣṣāṭ (40) an-nabāt wa-durūb anwa‘ al-mufradāt. For the more than 1200 drugs mentioned, he compiled “thousands of synonyms from about a dozen languages.” Abū Manṣūr Mauhūb b. Ahmad al-Ǧawālīqī, a philologist from Baghdad (d. 539/1144) devoted one of his books to foreign and loan words in Arabic (Kitāb al-Muʿarrab). In a relatively extensive Arabic-Persian dictionary entitled as-Šāhīfā al-‘adrā‘, which has so far remained quite unknown, one Muhammad b. ‘Umar an-Nasafi (6th/12th c.) compiled material from the related works of two predecessors, the Kitāb al-Maṣādīr by al-Ḥusain b. ‘Ali az-Zauzanī (486/1093) and the Kitāb as-Sāmī fi l-asāmī as well as al-Ḥādi li-š-sādī by Ahmad b. Muḥḥammad b. Ahmad al-Maṭārī (518/1124).

Finally the progress made during the 6th/12th century in the field of military technology shall be mentioned. A book brought to the attention of the interested public in 1948 by Claude Cahen yields valuable information on this matter, rendering various theories and assumptions by historians of this subject obsolete. This book, entitled Taḥṣīrat arbā‘ al-albāb, was written under the Ayyubid Sultan Şālahaddin (Saladin, r. 569/1174-589/1193), by Murḍā b. ‘Ali b. Murḍā aṭ-Ṭarsūsī (infra V, 94 passim). Amongst other

für Geschichte der Arabisch-Islamischen Wissenschaften in Frankfurt and reprinted as: Islamic Geography, vols. 2-8.


219 al-Idrīsī possibly took al-Birūnī as a model, who cites in his book of drugs, Kitāb as-Ṣaidana, names for many drugs in about ten languages, amongst them “almost always Greek, Syriac, Persian, Indian, but often also Hebrew and the languages of Central and South Asia (Khwaremosian, Balkhian, Tokharian, Zabulian, Sijistani, Sindhi, among others),” see M. Meyerhof, Das Vorwort zur Drogenkunde des Bērūnī, in: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin (Berlin) 3/1933/157-208, esp. p. 170 (reprint in: Islamic Medicine, vol. 96, pp. 171-240, esp. p. 184).


221 The only manuscript known to me is in Istanbul, Topkapi Sarayi, III. Ahmet 2707 (649 H.), v. the catalogue by F. E. Karatay, vol. 4, p. 29.

222 Judged by the type of blessing formula which follows the name az-Zauzanī and the absence of a blessing formula in the case of al-Maṭārī, an-Nasafi appears to have been a younger contemporary of the latter.


225 I do not take into account the book Muqaddimat al-adab by Mḥmūd b. ‘Umar az-Zamaḥṣarī (d. 538/1144) as an Arabic-Persian dictionary of the 6th/12th century. The Persian, Turkish and Mongolian glosses which are available in various manuscripts seem to be later interpolations, see Heinz Grotzfeld, Zamaḥṣarī’s muqaddimat al-adab, ein arabisch-persisches Lexikon? in: Der Islam (Berlin) 44/1968/250-253.
things, this book describes a ballistic crossbow (*qaws az-ziyār*) said to be the largest, the farthest in reach and the most effective ever made. A geared winch mechanism allowed for its large bow, made of several layers of wood and horn glued together, to be drawn by merely one or two men (instead of about twenty). In the 13th century this type of crossbow also started to appear in the West. This probably kindled Leonardo da Vinci’s fantasy, who drew a gigantic specimen of such a weapon (infra V, 119). It seems that the crusade invasions gave the impulse for the Muslims of Syria and Egypt to search for the most effective means of defence possible. The process of developing such weaponry continued into the 7th/13th and 8th/14th centuries.

**The 7th/13th Century**

In all branches of science, the 7th/13th century provides evidence of creativity in the further development of those disciplines that were cultivated in the preceding century. Yet it is characteristic of this century that the subject matters inherited from earlier generations were as far as possible subjected to systematization. They were established for the first time as strictly defined disciplines or revised in order to account for the progress made in the course of time. To begin with, we may say that the last-mentioned type of continuation process offers its best examples in Nasiraddin at-Tusi’s revisions (*tahrīr*) of important works by Greek and Arabic scholars.

An unfortunate opinion, brought into circulation at some point or other in complete ignorance of the history of Arabic-Islamic science and contradicting historical facts, states that this century already carried in it the beginnings of stagnation. The opposite is true.

The progress made in the theoretical branch of astronomy shows itself in the attempts to reform the Ptolemaic planetary models (supra, p. 25), once started by Ibn al-Haitham and Abū ‘Ubaid al-Ğūzağānī. In order to restore the principle of uniform circular motion in the orbits—a principle that Ptolemy had violated with the introduction of the equant into his planetary model—Naşiraddin at-Tusi made a ground-breaking attempt. In his model he retains the centre of the equant, so that the length of the eccentricity is equal to the diameter of the epicycle, while the mid-point of the eccentricity becomes the centre of the deferent, along which the centres of the epicycles of planets move from the east to the west, covering the same distances (towards the east) in the same periods. Naşiraddin eliminates the resulting violation of the uniformity of motion by introducing a model of double epicycles in which a smaller circle (with a radius equal to half of the radius of the larger circle and therefore half of the length of the eccentricity) rotates inside a larger circle (between its centre and the circumference) in the opposite direction from west to east.

Naşiraddin bases his model on an original lemma which states:

> In a circle, let a small circle roll. If its radius is half that of the large circle, then any point on the small circle, while rolling, describes a diameter of the large circle.

This theorem appears later in the works of Copernicus (d. 1543), Ludovico Ferrari (d. 1565) and Philippe de La Hire (d. 1718).

Shortly after Naşiraddin at-Tusi, Mu’ayyaduddin al-‘Urđi (fl. before 670/1272) and Qubaddin aš-Širāzī (d. 710/1311) developed two new models resembling each other to a large extent, where the younger scholar seems to...
to be depend-ent on the older. This resulted in an interesting model for Mercury.

Amongst the most remarkable achievements of the 7th/13th century in the field of astronomy ranks the foundation of the observatory at Maragha south-east of the Lake Urmia. The project was accomplished under the leadership of Naṣiraddin at-Ṭūsī between ca. 657/1259 and 668/1270 upon [42] commission of Hūlāgū, founder of the western Mongol empire, by a group of astronomers who originally worked in Baghdad and Syria. With a main building planned in large scale for the purpose of astronomical observation and with large instruments, some of which built for the first time, this undertaking was of epochal importance in the history of observatories in the Arabic-Islamic culture area. We can trace its after-effects not only in the Islamic world until the 16th century but also in Europe, where they began in the middle of the 16th century.

The spirit of logical systematization and elaboration of the work accomplished by the predecessors is characteristic of this century. One of the most significant examples of this is provided by Naṣiraddin at-Ṭūsī in his Kitāb aš-Šakl al-qattā‘ with which he established trigonometry as an independent discipline. For a long time this achievement had been credited to J. Regiomontanus, until, towards the end of the 19th century, A. von Braunmühl pointed out the facts of the matter (infra III, 135f.). The polar triangle, or supplementary triangle, a basic element of spherical trigonometry which appears in Europe for the first time in the work of François Viète (1540-1603), goes back to Naṣiraddin as well. Although it had already been introduced by Abū Naṣr b. ʿIrāq, it was Naṣiraddin who gave a first clear description of it.

A revision of Euclid’s Elements not identical with the one by Naṣiraddin at-Ṭūsī but most probably going back to his century, was published in Rome in the year 1594 as a work by at-Ṭūsī. It, too, betrays the spirit specific to the Arabic-Islamic science of the 7th/13th century and strongly influenced the subsequent generations of mathematicians. In the chapter Geometry of this catalogue (infra III, 127), at-Ṭūsī’s role in connection with the further development of the theory of parallels, which in the 18th century led to non-Euclidian geometry, will be mentioned; besides this, mention must be made here of his contribution to the theory of compound ratios. His theory of the “Measurements of Proportions” reappears in the “Denominations of Proportions” by Gregorius a Sancto Vincentio (1584-1667).

The achievements of the same century in the field of mathematical geography were prodigious both in quantity and quality, and were often of ground-breaking significance.

In the western part of the Islamic world, Abu l-Ḥasan al-Marrākušī (b. around 600/1203, d. ca. 680/1280) described a method for establishing the time difference between localities and thereby their longitudinal difference through the altitude of fixed stars above the eastern or western horizon, to be measured with an astrolabe.

Al-Marrākušī also described a procedure which enables the solution of this problem without the use of the astrolabe. The problem and its solution, described in the 10th volume of my Geschichte des arabischen Schrifttums, involves in its most general form the calculation of the hour-angle of a star from its altitude and azimuth, the rotation

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of the celestial dome from its transit through the meridian, and the declination.\textsuperscript{244}

[43] Yet neither the method of determining the hour-angle nor the use of spherical trigonometry for the determination of longitudinal differences appear for the first time in al-Marrākuşī’s writings. Al-Bīrūnī had already placed the rules for the spherical triangle, discovered by his teachers, in the service of mathematical geography. Amongst subsequent generations we find—tangibly for us in the case of al-Marrākuşī—a further development in which all trigonometric-astronomical tools are improved in a systematic manner for a precise determination of local time through the observation of fixed stars. This technique of astronomical observation, in which correct ascensions and declinations increasingly come to the fore as a system of reference, is encountered in the West with Tycho Brahe in the second half of the 16th century.\textsuperscript{245}

It seems that Abu l-Hasan al-Marrākuşī actually applied the special case of determination of longitude in question for geographical purposes. He left us a table of coordinates comprising about 130 localities. The importance of this table for the history of geography lies in the fact that it contains corrected latitudes and much improved longitudes of coastal towns of the Mediterranean and of further localities on the Iberian peninsula and in Northern Africa; from these it can be established that the length of the Mediterranean—with an improvement of about 19° as compared to Ptolemy’s geography and of about 8° compared to the result of the Ma’mūn geographers—approaches the modern value up to 2° or 3°; the longitudinal difference between Toledo and Baghdad found as 51°30′ also shows a similar far-reaching improvement.

It goes without saying that such a profound improvement of the coordinates of a vast geographical area stretching from Spain to Baghdad could not possibly have been achieved by a single person and not even in one single generation. Abu l-Hasan al-Marrākuşī indeed makes no such claim. On the contrary, he points out that he marked his own coordinates with red ink in his autograph in order to distinguish them from older ones.\textsuperscript{246} In the middle of the 19th century, the geography historian Joachim Lelewel\textsuperscript{247} recognised the significance of these corrections and described them as a “reform of geography”. He noticed that through the “extremely useful operation” Spain lost its “disproportionately large dimension” found in earlier cartography, whereby “the sides of Africa were pressed southwards while a large part of Spain moved north and protruded westwards.” Through al-Marrākuşī’s corrections, all the localities in the Maghrib are raised in latitude and thus given their actual positions.

It seems to be adequately documented today\textsuperscript{248} that the beginnings of astronomical-geographical attempts at mathematically surveying as much of the areas west and east of Baghdad as possible took place in the first half of the 9th century, independently from one another. One of the consequences of the measurements taken in the western areas was that the prime meridian passing through the Canary Islands, which was adopted from Marinus/Ptolemy, had to be shifted westwards by 45°25′, i.e. to 28°30′ west of Toledo in the Atlantic Ocean. After this correction of the longitudes in the western part of the Islamic world, the corrected values for Rome and Constantinople appear in one of the oldest surviving tables as 45°25′ and 59°50′ respectively. Subtracting 28°30′ from both (Rome 16°50′; Constantinople 31°20′), these values are, compared to the modern ones (Rome 16°30′; Istanbul 32°57′) merely 20′ too large or 1°37′ too small respectively. The longitude of Baghdad was now established at 80° with a dif-

\textsuperscript{244} v. F. Sezgin, op. cit., vol. 10, pp. 168-171
\textsuperscript{245} v. F. Sezgin, op. cit., vol. 10, p.171.
\textsuperscript{246} v. F. Sezgin, op. cit., vol. 10, p.171.
ference of 51°30' to Toledo and a distance of 10° to the central meridian in the east.  

In his book Asie centrale (1843) Alexander von Humboldt pointed to the fact that the duplicate prime meridians are also mentioned in the tables of the Libros del saber de astronomía (compiled between 1262 and 1272 CE upon commission of Alfons of Castile). We are in the position today to demonstrate that tables prepared according to both prime meridians found their way into Europe beyond Spain from the first half of the 12th century. At first those tables appeared slowly, but later, from around the beginning of the 14th century into the 18th century, started to mushroom and amount to several hundred; upon examination they turn out to be either corrupt copies or mixed tables derived from various Arabic originals which contained data according to either of the two prime meridians and which in turn sometimes still drew on Ptolemaic tables.

We may also refer to the fact, dealt with at length in the Geschichte des arabischen Schrifttums, that European graduated world maps from the second decade of the 16th century up to the 18th or even 19th century betray a dependence on longitudes gleaned from either one type or a mixture of Arabic tables. Yet we must stress that this statement does not imply that those maps were drawn by Europeans according to coordinates found in Arabic tables. They are copies or compilations of maps of unequal quality that where occasionally brought to Europe from the Arabic-Islamic world.

The substantial corrections of longitudes in the area between the western border of the oikoumene and Baghdad which were achieved by geographers and astronomers of the western school of Islamic science from the 5th/11th century onwards, at first escaped most eastern Arab scholars. Although in a few tables from the eastern part of the Islamic world such corrections are found even in the 5th/11th century, they are restricted to places located west of Baghdad. No serious attempt at unification of the corrections of the longitudes to the west as well as to the east of Baghdad obtained since the middle of the 5th/11th century, i.e. to transform also the eastern longitudes counted from Baghdad according to the prime meridian 28°30' west of Toledo, was made for almost three centuries.

This breakthrough, revolutionary for the history of cartography, finally occurred as a result of the collaboration of the “eastern” astronomer Naşraddin at-Tūsī and a scholar from the west, Muḥyiddin Yahyā b. Muḥammad b. Abī ʾŚukr al-Mağribī (d. ca. 680/1281) shortly before 670/1272 at the newly founded observatory of Maraga. The integration of longitudes was carried out consistently in the astronomical tables of the two scholars, namely, the az-Zīq al-ʿIlhānī and the Adwār [45] al-anwār mada d-duhūr wa-l-akwār.  

Considering that the extensive comparative geographical tables of places by Abu l-Fidāʾ Ismāʿīl b. ʿAli (d. 732/1331) do not yet include the substantial corrections on the area west of Baghdad, we are indeed justified in calling the integration of the coordinates as achieved in Maraga a revolutionary breakthrough in the history of cartography. The scope of this project is illustrated by two examples. The longitudinal difference between Toledo (28°30') and Ghazna

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252 vol. 11, pp. 85-154.
(104°20') is reduced to 75°50' with a relatively minor error of 3°28' as compared with the modern value of 72°22'. The difference between Rome (45°27') and Daibul in India (102°30') is 57°03' with an even smaller error of 1°48' compared to the modern value of 55°15'. Only from the 19th and 20th century did European cartographers gradually succeed in correcting these longitudinal differences further.

The first world maps drawn according to the fundamentally corrected coordinates were presumably produced as early as in the second half of the 7th/13th century. There is evidence leading to such an assumption involving a presently lost manuscript which perhaps was an autograph of the astronomical at-Ta'kira fi l-hai'a by Naṣiraddin at-Ṭūsī which appears to have contained such a world map. A copy drawn after the original by Joseph Needham and published in 1959, though a mere sketch, shows a basic depiction of the oikoumene surrounded by the ocean, which is more advanced than that on the Ma'mūnian world map and the one by al-Idrisi; this includes the fact that the west-eastern extension of the oikoumene is considerably reduced.

According to a report found in an historic work from the turn of the 7th/13th to the 8th/14th century to which historians of cartography have failed so far to pay any attention, a world map was drawn upon a papier-mâché globe at the Baghdad observatory under Naṣiraddin at-Ṭūsī in the year 664/1265. This agrees with a passage in the Records of the Yuán-dynasty by Sòng Lián (1310-1381 CE) referring to astronomical instruments imported into China from the West (i.e. the Central Asia). It describes six astronomical instruments and a terrestrial globe which were presented in the year 1271 (i.e. three years before Naṣiraddin at-Ṭūsī died) by one Ǧamāladdin to the Mongol sovereign Qubilai Hān. The terrestrial globe is said to have been made of wood, the ‘seven waters’ on it drawn in blue-green and the three continents with their rivers, lakes etc. are said to have been drawn ‘bright’ (white). ‘Small squares’ are said to have been marked in such a way that it was possible to calculate the size of regions and the distances of all routes. Those ‘small squares’ doubtless refer to the network of meridians and parallels of a graticule. We may also mention that the envoy Ǧamāladdin has been identified as the first director of the observatory founded by Qubilai in the Mongol realm. Moreover, Ǧamāladdin authored a geography of the entire dominions. However, only a few fragments of this comprehensive work have survived incorporated into later compilations.

[46] There is still further evidence in favour of our assumption that the oldest maps of the world that reflect the substantially improved coordinates of the 5th/11th century were produced as early as in the second half of the 7th/13th century. They will be mentioned in the context of the geographical endeavours of the 8th/14th century. Concluding the discussion of noteworthy achievements of the 13th century, the emergence of perfect or near-perfect maps of the Mediterranean and of the Black Sea shall be mentioned. They are commonly referred to as “portolan charts” by modern history of cartography. The origin of the oldest maps of this type known in the European culture area is dated around the turn of the 13th to the 14th century. The question of their origin has been discussed for about the last 150 years. With the exception of a few Arabists who noted a certain affinity of these charts with al-Idrisi’s world map, the issue has so far been treated in complete ignorance of the achievements of the Arabic-Islamic culture area in the field of mathematical geog-

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356 v. F. Sezgin, op. cit., vol. 12, p. 36, map no. 15.
357 v. ibid, vol. 10, pp. 138 ff., 310.
358 v. ibid, vol. 10, pp. 310-311.
359 On the sources, v. ibid, vol. 10, pp. 311-312.
360 v. ibid., vol. 10, p. 312.
raphy. Hence it was understandably not known that in the Arabic-Islamic culture area the west-
eastern dimensions and distances between, e.g., Tangier and Rome, Toledo and Rome, Rome and 
Alexandria or Rome and Constantinople were already established with an accuracy that comes close to the modern values. These accur
rate data constitute the decisive element serving to elucidate the progress made between the fairly realistic shape of the Mediterranean in Idrisí’s map and the shape of the so-called perfect portolan charts with their linear networks. In several chapters of the volumes 10 and 11 of my Geschichte des arabischen Schrifttums, I have tried to explain my opinion of a long historic evolution of the cartographic depiction of the Mediterranean. Various cultures made their contributions in the course of that development, the finally leading to the so-called portolan charts which can be ascribed to the Arabic-Islamic culture area. The circular world map, appended by Brunetto Latini to his Livres dou tresor (ca. 1260-1266), is an important document for the stage of development between al-Idrísí’s world map (549/1154) and the almost perfect shape of the Mediterranean and the Black Sea with the adjacent areas, achieved presumably in the 2nd half of the 7th/13th century. As Florentine ambassador in Toledo and Sevilla, Latini had the opportunity to acquaint himself with the adoption of Arabic-Islamic sciences which was then in full swing. He also helped Dante Alighieri deepen his knowledge of Islam. His world map appeared without precedence in Italy and differs fundamentally from the old Imago mundi maps circulating in 13th century Europe. It seems to be a copy of a model from the Arabic-Islamic culture area, ultimately going back to the Ma’mûn map, yet showing a certain progress regarding the shapes of the Mediterranean, Asia Minor and Africa. It does not however reflect the advances made in the depiction of North, North East and Central Asia known from the Idrisí map. It must be also noted that the Brunetto Latini map is southern-oriented as was the Arab custom. The representation of mountains and highlands in elevation corresponds to the same practice in the Ma’mûn map.262

Besides the Brunetto Latini map, which we assume to be a copy of a map from the western part of the Islamic world, there are a few more maps that outline the progress made in the second half of the 7th/13th century in the depiction of Asia. They are the five maps which Marco Polo is said to have brought back from his journey. [47] Without entering the discussion on whether or not Marco Polo actually reached China, we point out that on his outward journey (1272) he visited western Iran under the reign of the Ilkhans and on his homeward journey (1294/1295) he visited Tabrîz. This was the region where mathematical geography and, based on it, the new cartography was cultivated most intensively. In Marâga and later in Tabrîz, the capitals of the Ilkhans, new centres of the sciences arose from whence books, instruments, maps and further materials found their way to the West, mostly via Constantinople. The maps brought back by Marco Polo, the authenticity of which I have discussed in the Geschichte des arabischen Schrifttums are rather clumsy copies; however, they contain, on the one hand, the oldest cartographic representation of South Asia extant and, on the other, an orthogonal graticule showing the eastern edge of Asia at 140°. It is the eastern border of the oikoumene, which according to Ptolemy was at 180° and which was reduced largely to its true value by Arabic-Islamic astronomers only in the 7th/13th century.266

262 v. ibid, vol. 10, pp. 315-320.
264 v. ibid, vol. 10, pp. 315-319.
265 v. ibid, vol. 10, pp. 317-318.
266 v. ibid, vol. 10, pp. 317-318.
The type of world map developed in the Arabic-Islamic culture area in the second half of the 7th/13th century soon spread not only to Europe and but also to China. In the early 14th century, maps started to appear there that break with the conventional Chinese concept of the Earth’s surface and with the cartographic tradition. Towards the middle of the last century these maps came into the focus of research.\textsuperscript{257} When the surviving younger versions of those maps were examined, it came as a surprise that they show Africa in triangular shape, that they represent the configuration of the Mediterranean almost correctly, and that they, moreover, reproduce the Arabised names of about 100 places and countries in Europe and—as far as could as yet be identified—35 from Africa. The appearance of that type of map which “in its origins goes back to the years around 1300” in China has been explained by research almost unanimously with an Arabic model. This model is supposed to have been the graduated terrestrial globe which was brought from Marāğa to Da Du (Beijing) by the above-mentioned astronomer and geographer Ğamāladdīn in the year 1267, to be handed, together with six astronomical instruments, to the ruler Qubilai Ḥān. This assumption may be correct, but I am more inclined to believe that planispheric world maps from the east of the Arabic-Islamic world reached China—shortly after their appearance—as well. Certainly the numerous place names would fit more easily on maps than on a terrestrial globe.

I take the liberty of bringing to the notice of a wider circle of readers my cartographic-historic evaluation of those maps from the relevant volume of my \textit{Geschichte des arabischen Schrifttums}\textsuperscript{268} which appeared in 2000: “The eminently important historical fact in geography, namely that—more or less at exactly the same time at which a new type of world map and portolan chart appeared in Europe—the cartography of the Chinese, which until that time had restricted itself to China and parts of East Asia, broke with this tradition and extended the borders of its image of the world all the way to the Atlantic and from South Africa through to central Russia, whereby simultaneously an almost exact configuration of the Mediterranean and of the triangular shape of Africa became recognisable, is something which has not been taken into consideration in the discussion on the origin of the portolan charts as far as I am aware. The phenomenon of [48] this simultaneously-timed emergence of a practically identical new image of the world in Europe and China should, in my opinion, lead historians of geography to the assumption that a common model existed. Not only the Islamic cultural area provides us with sufficient cartographic and mathematical-geographical documents which prove that the sought after models are to be found in that period of the history of sciences which was shaped by that cultural area.”

The oldest surviving Arabic document of this latest stage of development is a map from the Maghreb.\textsuperscript{269} It shows the westernmost part of the Mediterranean with a complete configuration of the Iberian Peninsula and the western edge of Europe with some strips of the English and Irish coastline. This Maghribi map may be older than the oldest known “portolan chart” which is supposed to date from around 1300 CE. In any case, the first scholar who wrote about it, Gustavo Uzielli,\textsuperscript{270} introduced it as a work of the 13th century. A few years later Theobald Fischer,\textsuperscript{271} in the context of his work on medieval world and sea maps, was inclined to shift its origin to

\textsuperscript{257} v. F. Sezgin, op. cit., vol. 11, pp. 27-31.
\textsuperscript{258} v. ibid., vol. 10, p. 326.
\textsuperscript{259} F. Sezgin, op. cit., vol. 11, pp. 27-31.
\textsuperscript{271} Th. Fischer, op. cit., p. 220.
the end of the 14th century; and because of this, later research lost sight of one milestone in the history of development of the ‘portolan charts’. The pull of conventional mediaeval studies unfortunately quite often keeps researchers from addressing issues of the date and provenance of technological innovations and new scientific or philosophical concepts surfacing in Europe (outside Spain) from the 12th century onwards in the context of the reception and assimilation of Arabic-Islamic sciences in general. The case of the ‘portolan charts’ makes no exception.

In support of my view regarding the character and quality of the cartographic skills found in the Islamic world in the 7th/13th century, I would like to cite one more testimony for which we are indebted to one of the pivotal figures in this development. I am referring to the polymath Quṭbaddin āṣ-Širāzī (d. 710/1311) mentioned above (supra p. 41). In connection with matters of geography, included in his astronomical work at-Tuḥfa aš-šāhiya fī t-hai‘a, he deals with the cartographic depiction of the oikoumene and the difficulty of fitting indispensable details in small formats. To this end he proposes a practical method of laying out a simplified and schematized map of the Mediterranean. Together with the Black Sea, the Mediterranean is projected on a rectangular frame divided into 1200 squares. The longitudes and latitudes are measured in squares rather than degrees.

Apparent oceans and continents were distinguished by colour. In the first half of the 20th century some Arabists drew up such a schematic map on the basis of Quṭbaddin’s data (infra p. 49).

The shapes of North-Africa, the Mediterranean, the Black Sea and the depicted parts of Europe leave hardly any room for doubt that Quṭbaddin
already knew the accurate geographical representation of those areas as found in the portolan charts. In fact it is quite evident that Quṭbaddin took his data from a map at hand. In corroboration of this, we can cite the universal scholar Raṣidaddin’s (d. 718/1318) report [49] to the effect that Quṭbaddin aš-Širāzī presented a detailed map of the Mediterranean to the Mongol ruler Argūn on 13th Ša‘bān 688 (1 September 1289). On this map, the coasts, bays, and cities in the West and in the North and even details of the Byzantine territory were inscribed.

After discussing the progress made in cartography in the Islamic world during the 7th/13th century, we may now turn to an apex of geographical lexicography. I am referring to the “Geographical Dictionary” (Mu‘gam al-buldān) by Yāqūt b. ‘Abdallāh ar-Rūmī al-Hamawi[24] (b. 574/1178, d. 626/1229). Yāqūt was primarily a man of letters and a philologist. In the field of literature he wrote a number of noteworthy works, including his biographical dictionary of scholars entitled Iršād al-arīb or Mu‘gam al-udabā’, which counts amongst the most important works of its kind extant. In the field of geography, his lexical interest brought about two books. One of them, al-Muštarik waḍ‘an wa-l-muṣṭariq ṣaq‘ān of 623/1226, deals with geographical homonyms. The other one, Mu‘gam al-buldān, marks the climax of the literary genre of geographical dictionaries which had continued to develop in the Islamic world from the 4th/10th century onwards. Besides lexical sources, Yāqūt digested a number of titles of descriptive regional geography and mathematical geography as well as travelogues. Thus his work [50] became an invaluable source for the historiography of sciences and culture of the Arabic-Islamic world. In the commendable edition by Ferdinand Wūstenfeld (1866–1870), the book runs into 3500 pages.

Comparing Yāqūt’s book in quantity and quality with the first modern geographical dictionary to appear in Europe, the Latin Synonymia geographicā[25] by Abraham Ortelius (1578), gives a fairly good idea of the significant development of this branch of scientific literature in the Arabic language.

Turning to the field of medicine, a significant discovery in that century—which the historian of medicine L. Leclerc[26] referring to Syria, called a golden age of sciences, and medicine in particular—was that of the minor circulation of blood by ‘Alī b. Abī l-Ḥasan Ibn an-Nafīs al-Qurašī (d. 687/1288). Researching for his thesis[27] on Ibn an-Nafīs’ commentary on the surgery chapter of the al-Qānūn fi t-tibb by Ibn Sīnā, Muḥyiddīn aṭ-Ṭāwī, an Egyptian student, hit upon that fact in the year 1924. Thanks to several studies by Max Meyerhof and Joseph Schacht,[28] we know today that this discovery by Ibn an-Nafīs was borrowed by Michael Servetus (Miguel Servet) for his Christianismi restitutio (Vienna 1553); consequently the latter was considered its originator for centuries. Realdu Columbo (Realdo Colombo) in his De re anatomica libri XV (Venice 1559) also seems to have known about the discovery directly or indirectly from Ibn an-Nafīs. Ibn an-Nafīs’ description of the pulmonary circulation which

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he gave in his commentary to the *Qānūn* of Ibn Sīnā supposedly reached Europe through a translation by Andreas Alpagus (Andrea Alpago, d. ca. 1520).\(^{579}\) During a thirty-year stay in Syria, he had acquainted himself with Arabic language and medicine. On his return to Padua he took with him several Arabic books and translated, inter alia, Ibn Sīnā’s *Qānūn* into Latin, the same Canon which had already been translated by Gerard of Cremona.

With regard to yet another medical scholar of the 7th/13th century, research found clues of an important discovery. While staying in Cairo, the versatile physician and brilliant natural historian ‘Abdallatif b. Yusuf b. Muhammad al-Baghdadi (b. 557/1162, d. 629/1232) seized the opportunity to examine the skeletons of people who had perished during a plague epidemic and famine in the year 598/1202. He wrote about his observations and the results of his examinations in his anthropogeographical book on Egypt entitled *Kitāb al-Ifāda wa-l-i’tibār fi l-umār al-muṣāhada wa-l-hawādīth al-mu‘āyana bi-ard Miṣr*, in which he dealt, inter alia, \(^{51}\) with stones, flora and fauna, antiquities, architecture and the local cuisine. In his anatomical study of thousands of skeletons he revised the errors and inaccuracies of his predecessors, in particular of Galen. One of his findings was that the human mandible consists of one bone only, rather than two bones joined at the chin as Galen believed.\(^{280}\) In this context al-Baghdadi points out that the evidence of one’s own observation was more reliable than the doctrines of Galen, despite the high rank befitting the latter.\(^{280}\)

The maturity of the epoch with its widened horizon as well as the extent and the magnitude of the achievements accomplished in his culture area induced Ahmad b. al-Qāsim Ibn Abī Uṣaibī’a (d. 668/1270), a contemporary of the above-mentioned Ibn an-Nafis and ‘Abdallatif al-Baghdadi, to compose, within the scope of his resources, a universal history of medicine. The medical historian Edith Heischkel,\(^{281}\) even though she unfortunately characterises the epoch of the author incorrectly as “a late period of Arabic science in which existing knowledge was digested rather than being creative in its own right”, described quality and character of this work entitled ‘Uyūn al-anbā’ fi ṭabaqāt al-ʿāthibā’ quite appropriately: “He has set himself free from the bias of antique and Jewish myths, knowing that each and every culture has its own peculiar theory of the origins of medicine. In his view, each culture also has its own special medicine, one yielding place to another in the course of centuries. He doubted whether it was at all feasible to deem the medical science of any one people the oldest. The Arab, in whose native region cultures of diverse people from East and West fused, possessed the universal historical scope which no physician before him ever had; in the writings of Ibn Abī Uṣaibī’a the history

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of medicine is seen from the point of view of universal history for the first time.”

“… The Western historians of medicine had to go a long way until they finally came to these insights. Medical historians in the West observed, what the Arab cosmopolitan attitude had long before seen, only after they had overcome the authority of antiquity and of the Bible. 285

Finally, in the field of medicine of the 7th/13th century, the hospital built 683/1284 in Cairo by the Mamluk Sultan al-Malik al-Manṣūr Saifaddin Qalāwūn284 shall be mentioned. After the ‘Aḍudi hospital in Baghdad (372/981) and the Nūraddīn hospital in Damascus (549/1152), it was the latest and the most advanced of the three major hospitals in the Islamic world established by that time. In some respects it seems almost modern. Such progressive features are its medical organisation with specialised treatments, the playing of music to patients suffering from mental illness or insomnia, in-house medical training, [52] an elaborate administration, financial security through sufficient income from an endowment (with quite interesting conditions specified in the foundation deed) and, finally, the building itself and its equipment. This hospital with its dome (which seems to have collapsed after the 11th/17th century) and its cruciform ground plan is believed to have served as the model for similar hospitals in Europe. 285

The 7th/13th century also marks a climax in music theory as part of the natural sciences. After the assimilation of predominantly late antique sources by Ya‘qūb b. Ishāq al-Kindī in the 3rd/9th century, and the masterly adoption of “classical” Greek sources in the service of a distinctly Arabic musical theory by Abū Naṣr al-Fārābī and Abū ‘Ali Ibn Sinā in the 4th/10th and early 5th/11th century, it was Ș afiyaddin ‘Abdalnu‘min b. Yūsuf al-Urmawi (d. 693/1294) whose influential Kitāb al-Adwār, 286 a systematic compendium of musical theory, summarises and winds up the recent development. H. G. Farmer 287 called him the founder of the “Systematist school” with mathematical-physical inclination, which existed until around 900/1500. In al-Urmawi’s Kitāb al-Adwār we encounter for the first time the division of the octave in seventeen unequal degrees as a fully developed system. 288

In the humanities I would like to mention the important achievement by Yūsuf b. Abī Bakr as-Sakkākī (b. 555/1160, d. 626/1229) in the two interdisciplinary subjects of linguistics, ‘ilm al-ma‘ānī and ‘ilm al-bayān. The former I would translate ‘grammar of style’, and for the latter I borrow Wolfhart Heinrich’s 289 term, ‘pictorial language’ (Bildersprache). ‘Abdaļqāhir al-Ġurgānī (d. 471/1078, cf. infra p. 33) in his Dalā‘īl al-‘īgāz and the Asrār al-balā‘a had created the foundation upon which as-Sakkākī elaborated his Miftāḥ al-‘ulūm 30 with logical systematisation into strictly defined disciplines. It seems an intermediate stage in this process

had already been reached by the universal scholar Muhammad b. ‘Umar Fahrdinn ar-Razi\(^{201}\) (b. 543/1149, d. 606/1209) in his *Nihayat al-iğaz fi dirāyat al-i’ğāz.*\(^{202}\)

In the same 7th/13th century, in which progress was made in almost all fields of Arabic-Islamic historiography, world history was treated with special interest. The monumental chronicle by ‘Izzaddin ‘Ali b. Muḥammad Ibn al-‘Atīr\(^{203}\) (b. 555/1160, d. 630/1233) was written in the first quarter of the century; under the title *al-Kāmil fī i-ta’rīḥ*, it deals with world history from genesis up to 628/1231. As far as we are aware, this is the most extensive and the most significant work of its type written since the world history by Muhammad b. Garir at-Tabari (d. 310/923, supra p. 18). The author appears to be [53] extremely objective and reliable. Yet it is not correct and even unfair to call him “perhaps the only true historian of Islam in the early Middle Ages.”\(^{204}\) In the same spirit, ‘Ali b. Anqāb Ibn as-Sā‘i,\(^{205}\) (b. 593/1197, d. 674/1276), an historian from Baghdad, wrote another chronicle of the world entitled *al-Ǧāmi‘ al-muḥtaṣar fī ‘unwān at-ṭawārîḥ wa-‘uyūn as-siyar* in twenty-five volumes of which only the ninth is extant. Judged by this fragment, Ibn as-Sā‘i’s book is equal to the high rank of his predecessor’s.

In military technology, the ongoing necessity of defence against attacks by crusaders brought about further advances in weaponry in this century as well. The most important innovation in this field was the development of fire-arms using gunpowder. The question has not yet been solved whether the knowledge of gunpowder reached the Arabic-Islamic culture area from China or whether it was developed independently. It is however probable that its driving power was recognised and used for military purposes in the Islamic world, even if fireworks were known in China at an earlier date. As far as we know, the Arabs had used cannons since the second half of the 7th/13th century (infra V, 99); it is possible that the use of hand grenades also goes back to this century (infra V, 101 ff.).

**The 8th/14th Century**

Turning to the 8th/14th century, we realise that science in the Islamic world did not lose momentum in this period, in spite of all the turbulent political events. Through the loss of a substantial part of Andalusia, its scientific contributions, which had been on a high level for centuries, were diminished but did not yet cease.

In the field of astronomy the issue of Ptolemy’s theory violating the principle of uniform planetary motions, which had been addressed by Ibn al-Haitam in the 5th/11th century and which had once more become topical in the 7th/13th century, engaged the disciples of Naṣīraddin at-Ťūsī in the 8th/14th century. Yet the most important model aimed at restoring the principle of uniform motion was conceived, as far as we know, in Syria. Its originator was ‘Ali b. Ibrāhim Ibn aṣ-Ṣāṭir (d. ca. 777/1375). In his models he does away with eccentricity and lets the vector (one for each planet) start from the centre of the universe while adopting Naṣīraddin at-Ťūsī’s concept of dual epicycles. Particularly important is his model of Mercury in which he makes use of a smaller epicycle than Ptolemy. He achieved excellent results in his attempt to improve the inherited models of the lunar motions. While restoring the uniform circular motion of the Moon, he corrects the glaring defect in Ptolemy’s model, in which the latter had exaggerated the variations of the Moon-Earth distance.\(^{206}\)

\(^{201}\) ibid, vol. 1, p. 506, suppl., vol. 1, p. 920.

\(^{202}\) W. Heinrichs, op. cit. p. 184.


\(^{205}\) v. C. Brockelmann, op. cit. suppl., vol. 1, p. 590.

\(^{206}\) F. Sezgin, op. cit. vol. 6, p. 36.
Recent research has established that Copernicus knew the models of Ibn as-Sātir and his Persian predecessors and contemporaries and that their influence on him must have been profound. The points in common between Copernicus and his Arabic-Islamic predecessors, as found so far, can be summarised as follows:

1. Copernicus as well as Naṣiraddīn at-Ṭūsī and Qūṭbaddīn as-Sirāzi accept without reservation the principle that each planetary model must be based on a mechanism in which equal distances are covered by equal vectors with equal angular velocity.

2. Copernicus and his Arabic predecessors feature the mechanism of a double vector with radii equal or half the eccentricity in their planetary models, in order to emulate the function of the equant.

3. Copernicus’s model of the Moon is the same as that by Ibn as-Sātir; both differ substantially to Ptolemy’s model in their parameters.

4. With minor alterations in the length of the vectors, Copernicus’s model of Mercury is the same as Ibn as-Sātir’s.

5. Copernicus employs the mechanism of the double epicycles of at-Ṭūsī in the Mercury model, as does Ibn as-Sātir.

According to the latest research, the new Arabic-Persian theories concerning the motion of the planets did not reach Copernicus via Latin translations, but through Byzantine mediation from Tabriz und Marāğa via Trabzon and Constantinople. For instance, the two Polish scholars Sandivogius of Czečch (1430) and Adalbertus of Brudzevo (1482), in their commentaries respectively to Gerardus’s *Theoricae planetarum* and Peurbach’s *Theoricae novae planetarum* display a fair knowledge of the above mentioned planetary theories from the Arabic-Islamic culture area; therefore, by the 15th century, these theories must have been known in Cracow.

Amongst the most important astronomical achievements of that age is a type of astrolabe which had been constructed in Syria by Ahmad b. Abī Bakr Ibn as-Sarrāq (d. ca. 730/1330). The instrument (infra II, 119) combines in itself the functions of a normal astrolabe and those of the universal plate as had been developed in the western part of the Islamic world. With this instrument a stage of development in the construction of astrolabes had been reached which henceforth stood unsurpassed, both in the countries of Islam and in Europe (infra II, 84).

In mathematics, a remarkable development occurred in the 7th/13th and the 8th/14th centuries in western North Africa. It involved the knowledge and application of algebraic symbolism that remained—as far as we know now—unknown in the eastern parts of the Islamic world. It is primarily found in the works of Ahmad b. Muhammad Ibn al-Bannā’ al-Marrākušî (b. 654/1256, d. 721/1321) and his grand-disciple, Abu l-‘Abbās Ahmad b. Ḥasan Ibn Qunfūḍ (b. 731/1331 or more likely 741/1340, d. 809/1406 or 810/1407). That Ibn al-Bannā’ had, according to his book *Raf’ al-hiğāb*, had [55] the mathematicians Ibn Mun‘im (Ahmad b. Muhammad

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298 v. F. Sezgin, op. cit. vol. 6, pp. 55-56


al-’Abdari⁵⁷) and al-‘Ahdab as his predecessors in the knowledge of algebraic symbolism was mentioned already by the well-known historian Abdarrahmân Ibn Hâldûn (d. 808/1406). This is corroborated by the treatises Fiqh al-hisâb by Ibn Munîm and Ra’î al-hiğâb by Ibn al-Bannâ, which were discovered in the last decade of the 20th century. Ibn al-Bannâ excelled with further important contributions, among them an approximation formula for the extraction of the square root.⁵⁸ For this matter he distinguishes between two cases, viz. “whether, after \(\sqrt{a^2+r} \approx a\) has been found, \(r\) turns out to be smaller or equal, or bigger than \(a\). If \(r \leq a\), one should equate \(\sqrt{a^2+r} = a + \frac{r}{2a}\) on the other hand, if \(r > a\), for better approximation one should equate \(\sqrt{a^2+r} = a + \frac{r}{a + 1}\). In formulating this, Ibn al-Bannâ no doubt relied heavily on his predecessor Muhammad b. ‘Abdallâh al-’Aṣâṣân (7th/13th ec.).⁵⁷ It is possible that the method for

the extraction of the square root by the Spanish mathematician Juan de Ortega (d. ca. 1568) is also connected with this.⁵⁸

From the fields of physics and technology, a remarkable clock should be mentioned, constructed by the above-mentioned Ibn aṣ-Ṣâṭîr, and described by the historian Ḥâlîl b. Aibak aṣ-Ṣâfâdî (d. 764/1363). Aṣ-Ṣafadî visited Ibn aṣ-Ṣâṭîr in Damascus to see this device invented by the latter and described it in the following words:⁵⁹ It “was positioned vertically against a wall, … had the shape of a bow (qantara) and measured approximately 3/4 ells … it ran day and night, without sand and without water and followed the motion of the celestial sphere, according to a special regulation, … indicating both equal and temporal hours.” This brief description leads us to the assumption that it might have been a weight driven mechanical clock.

In the 8th/14th century the Arabic-Islamic world area proved to be as creative as ever. Hence, in the field of optics, this century produced one of the most important scholars of the time. We are referring to Kamāladdîn Muḥammad b. al-Ḥasan al-Fârisî (b. 665/1267, d. 718/1318), otherwise known [56] as an outstanding physicist and mathematician. He wrote a monumental commentary, Tanqîh al-Manâzîr, on the “Optics” of Ibn al-Haitam (supra p. 29 ff.), which has not yet been exhaustively studied; in it we find an epochal explanation of the

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⁵⁶ M. Cantor, Vorlesungen über Geschichte der Mathematik, op. cit. vol. 1, p. 808.


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phenomenon of the rainbow the like of which his predecessors Ibn al-Haitham and Ibn Sinâ in the 5th/11th century, despite their attempts, had not been able to give (infra III, 166 ff.). In Kamâladdîn al-Fârisî’s opinion, the perception of a rainbow is caused by the optical behaviour of fine transparent spherical drops close to each other in the air, through double refraction and single or double reflection of the sunlight as it enters into and comes out of the individual drop. Kamâladdîn came to this conclusion after a series of systematic experiments conducted with a spherical ball made of glass or rock-crystal (infra III, 166).

One of the most significant results of Kamâladdîn’s research in the field of optics known so far is his theory of the image seen in the pupil. Matthias Schramm first noticed that Kamâladdîn “rejected Galen’s explanation as incompatible with the principles of optics” and investigated the true state of affairs by means of controlled experiments. To this end he used a mutton eye. Doing so, “he was the first to establish incontestably the reflection from the outer surface of the lens and he gave an excellent explanation in terms of his theory.”

With regards to the history of reception of Arabic-Islamic sciences in the West, it is of particular significance that Kamâladdîn’s explanation of the phenomenon of the rainbow appears again with a few minor alterations in the treatise De iride et radialibus impressionibus by Dietrich of Freiberg (Theodoricus Teutonicus), a little known Dominican monk in the first decade of the 14th century. In ignorance of—or perhaps ignoring—the process of reception and assimilation of Arabic-Islamic sciences in the West the physicist G. Hellmann in the year 1902 described the presentation of the rainbow-theory in Dietrich of Freiberg’s book as “the greatest achievement made in the Occident in this matter during the Middle Ages.”

Not long after this rampant review of Dietrich’s treatise, Kamâladdîn’s work became known in the circles of E. Wiedemann’s disciples and the question of a possible connection between Kamâladdîn and Dietrich was considered. This, of course, was at a time when the channels of the reception- and assimilation-process and its consequences were not understood as well as they are today. One of the explanations—proposed by Otto Werner in his study on Leonardo da Vinci’s physics, from the year 1910—is of general interest beyond the specific matter in question. It occurred to Werner that Kamâladdîn’s book must have been known in the Occident and was even used by Leonardo da Vinci. He also saw a close connection between Kamâladdîn and Dietrich (infra III, 169 ff.). I myself have no doubt that Dietrich of Freiberg must have become acquainted with Kamâladdîn’s achievements either directly through his book or during a stay in the Islamic world. The common features in fundamentals as well as details are so numerous that they cannot possibly be independent achievements. The first half of the 14th century is indeed to be characterised as a period when the sciences of the Arabic-Islamic world found their way quickly from Northern Africa to France and Italy, and from Syria, Anatolia and Persia directly or via Constantinople to Italy and Central Europe. Mediators from the clerical orders, particularly the Dominicans, proved particularly able in this process of reception and earned great merit.


In the field of medicine, a clear insight into the nature of infections, amongst other achievements, calls for our attention. Several related treatises were written in Islamic Spain following the devastating plague that had infested the countries of the western Mediterranean in 749/1348. The following titles are amongst them: Muqni‘at as-sā‘īl ‘an al-maraḍ al-hā‘il by Muḥammad b. ‘Abdallāh Ibn al-Ḥaṭīb (b. 713/1313, d. 776/1374),335 Taḥṣil al-ğarad al-qāṣid fi taṣṣil al-maraḍ al-wāfīd by Ahmad b. ‘Alī Ibn Ḥātimah (d. ca. 770/1369)334 and Taḥqiq an-naba‘ ‘an amr al-waba‘ by Muḥammad b. ‘Alī aš-Šaqqū (b. 727/1327).335 The first two works, surviving intact, relate their authors’ experiences with the effects of contagion. The medical world was made aware of the importance of Ibn al-Ḥaṭīb’s treatise by Marcus Joseph Müller as early as in 1863 through an edition of the Arabic text, accompanied by its German translation. According to Max Meyerhof,336 the Arabic writings on the plague were far superior to those written in Europe between the 14th and 16th centuries. A few sentences from Ibn al-Ḥaṭīb may testify to this:

“The existence of contagion is established as a fact by experience, research, perception, autopsies and authenticated information, and those are the instruments of proof. Everybody who has seen the thing itself or gathered information about it knows that most of those who come into contact with people afflicted with the disease die and those with whom this is not the case remain healthy; furthermore that this disease occurs in a house or in a quarter because of a garment or a receptacle so that even an earring can cause the death of a person donning it and thus brings devastation upon the entire house; moreover that in one city the disease occurs in a single house and then blazes up in those individuals who have contact with the sick person, then in the neighbours and relatives and especially among those who [58] pay visits to the house of the sick person, so that the breach becomes wider and wider; furthermore that the population of sea ports enjoys perfect health until an infected man arrives from another country where the plague prevails notoriously and the date of the outbreak of the disease in the town coincides with the date of his arrival.”337

We encounter further evidence on the progress in medical science of those days in the Arabic-Islamic culture area in the comprehensive ophthalmologic textbook by Ṣādaqa b. Ḥabrīm al-Misrī aš-Šādīlī (2nd half 8th/14th c.) entitled al-‘Umda al-kuhlīya fi l-amrād al-bāṣa‘ariyya.338 In the sixth chapter of the first part concerning “the dissimilarity of animals’ eyes and the human eye and the peculiar features of the latter,”339 J. Hirschberg found “the nucleus


337 Translation by M. J. Müller, op. cit., pp. 18-19 (reprint pp. 54-55), with slight modifications


339 Geschichte der Augenheilkunde, vol. 2: Geschichte
of comparative anatomy and physiology of the visual organ” which was only to be found in scientific form in the textbooks of ophthalmology in the second half of the 19th century (infra IV, 17).

Finally from the field of medicine we should mention the Persian Tanksiqmāma-i Ilhāni dar funūn-i ‘ulūm-i hītā’ī, written at the beginning of the 8th/14th century and dealing with “Chinese sciences”. Its author was the Ilhānid grand vizier Rašīdaddin Faḍlallāh b. ‘Imādaddaula (b. ca. 645/1247, d. 718/1318). The book contains “not only an adequate account of lost books, but also provides an extremely arresting picture of this great vizier’s vast horizon and interests … According to the characterisation given in the introduction of the four predominantly medico-pharmaceutical books summarised in the ‘Tanksiqmāma’, the extant book turns out to be a Persian translation of a partly rhymed anatomical work which, after its supposed Chinese author, is here given the title ‘Wang Shu-ho’. It is, however, not the classical Mo-ching by the famous physician Wang Shu-ho (265-317 CE), but a work called Mo-chüeh, which deals with the modalities of pulse observations and the anatomy of the most important human organs. It originated in northern China at the time of the Kin-dynasty (1122-1234). With its numerous illustrations which undoubtedly go back to a Chinese original, the alleged ‘Wang Shu-ho’ is the oldest authentic example of a ‘graphic Chinese anatomy’ in the Near East, indeed in the entire western world.” The third book deals partly with drugs of ancient China and partly with other pharmaceuticals in the form of a drug-manual. To it Rašīdaddin Faḍlallāh, who was a physician by profession, supplied an appendix with “tables of Chinese drugs unknown to the Greeks, with a precise description of their usage and efficacy in the form of a book.”

[59] In the field of geography, interesting evidence survives from the 8th/14th century to demonstrate that the mathematical representation of the surface of the Earth and its cartographic depiction, fostered in the Arabic-Islamic world in the preceding centuries, reached a new level of quality. From the western part of the Islamic world we know the important table of coordinates, comprising 97 localities, by the astronomer and mathematician Muhammad b. ʻIbrāhīm Ibn ar-Raqqaṃ (d. 715/1315) of Murcia. The table shows that the fundamental correction of the longitudes, carried out in Andalusia and the Maghrib, had by that time been extended to a larger part of the oikoumene and that the length of the grand axis of the Mediterranean has been reduced to 44° and, consequently, is only 2° too long compared to modern values. Of course, the correction was not restricted to the length of the grand axis. It is apparent in the distances between the western border of the oikoumene and the places east of Baghdad as well. Other extant tables with significant corrections to the longitudes allow the assumption that these tables enjoyed a wide dissemination. One such table was discovered in Latin translation by the Spanish Arabist I. Millás Vallicrosa in the middle of the 20th century and is of particular interest in this context. It was most probably composed in the east Andalusian town of Tortosa (Ţurtûs), and it is surprising in that the reduction of longitudes has now been implemented for Baghdad as the prime meridian, even for the places in the west. This table has also reached us in a


313 K. Jahn, Wissenschaftliche Kontakte zwischen Iran und China in der Mongolenzeit, op. cit., pp. 201-203.
Portuguese version. It contains the coordinates of 31 places in Spain, Western Europe and the western Mediterranean. Although it is not free from spelling errors and misreadings, it provides important evidence of the great advances made in Western Europe not least with regard to Arab-Spanish cartography. London can be taken as an example. According to this table the coordinates for London, reckoned from Baghdad, are $\text{Long } 42^\circ, \text{Lat } 48^\circ$ (modern values $\text{Long } 44^\circ 26', \text{Lat } 51^\circ 30'$). The difference in longitude between London and Baghdad in Ptolemy shows an error of $18^\circ$, with the Ma’mün geographers it was still $9^\circ$, whereas in this table the deviation is merely $2^\circ 26'$. Further examples can be found in my Geschichte des arabischen Schrifttums; here I would like to emphasise that these corrections, essential for the history of mathematical geography, have so far remained completely unknown and thus did not play any part in the discussion on the origin of the new maps which emerged in Europe from the turn of the 13th to the 14th century.

In the process of the mathematical survey of the areas to the west of Baghdad, Asia Minor, which was under Byzantine rule, and the Aegean remained for a long time outside the reach of Arabic-Islamic geographers and astronomers. As far as we know now, this situation appears to have started to change from the end of the 6th/12th century. Surprisingly accurate and detailed maps of those areas and of the Black Sea begin to appear in Europe almost suddenly from the turn of the 13th to the 14th century; for example Giovanni da Carignano’s map. These maps can only be regarded as the result of astronomical observations and geodetic measurements made on location, over a long period of time and with governmental support. We know of some sparse coordinates of Asia Minor which seem to have been determined under Islamic rule in the 7th/13th century at the latest. Yet only an [60] early Ottoman table, probably from the first half of the 8th/14th century, provides us with the coordinates of 151 localities, an eighth of which are in Asia Minor; this table is found in the treatise on astrolabes by one ‘Abdalhalim b. Sulaimân at-Ţuqāti. The table documents the early participation of Ottoman scholars in the elaboration of the graticule, at least in Anatolia. It also justifies the assumption that by that time fairly accurate results were achieved in the mathematical survey of Asia Minor. The same accuracy is found also in the table’s coordinates for the Mediterranean. We observe, for instance, that the longitudinal difference Rome—Constantinople and Rome—Alexandria deviate surprisingly little from the modern values. Regarding the west-east and north-south dimensions of Anatolia we may refer to at-Ţuqāti’s values for Constantinople and for Ahlāt, the easternmost place in Anatolia. The longitudinal difference differs only by $1^\circ 29'$ from the modern value, and the latitude even by a mere $2'$. In order to give the reader an adequate idea of the significance of these values determined in the 8th/14th century, we may mention that the actual longitudinal and latitudinal difference between these cities was established only in the 20th century.

Arabic and Persian writings of the first half of the 8th/14th century yield so many relevant documents and data that we must assume that many local cartographers and geographers took for granted that in the making of accurate maps precise coordinates in longitude and latitude were indispensable. One of the most important examples known to me at this time involves the universal scholar Rašiddādin, whose work on Chinese medicine was mentioned above. His secretary, who was responsible for bringing the master’s books in the desired form, states that Rašiddādin’s geographical work described the seven climata, the parts of the known world, the seas and oceans, mountains, valleys etc. along with the degrees of longitudes and latitudes

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323 v. ibid, vol. 10, pp. 322-337.
found in the corresponding books, that the data were verified and that information was gathered from experts on the various countries in order that the data did not deviate from reality. We also learn that due to the size of the maps an extraordinarily large format was chosen for the book, since the maps “following the methods of the experts” were to be made “as clear and as comprehensible as possible” and “the places were also to be drawn onto the map as precisely as possible.”325

It is a pity that the cartographic material surviving from this period in the original languages—Arabic and Persian—is confined to a sketchy map covering the area from Anatolia to Central Asia included in the book Nuzhat al-qulūb by the Persian geographer and historian Ḥamdallāh al-Musta’fī (d. ca. 740/1340). The map326 stretches in length from 63° to 112° and in latitude from 16° to 45° north of the equator. The names of about 120 localities are placed within an orthogonal graticule. The user can read the coordinates from scales framing the map. The significance of this map lies in the fact that the graticule is based on the integrated west-longitudes—according to the above mentioned (p. 43 ff.) astronomers in Marāğa—reckoned from the prime meridian at $28^\circ30'$ west of Toledo. What’s more, the longitudes (leaving aside obvious slips), approach modern values up to 3° or 4°.

[61] One of the important contributions by the Arabic-Islamic world in the field of geography is the extensive travelogue by Muḥammad b. ʿAbdallāh Ibn Baṭṭūṭa (b. 703/1304, d. 770/1369), who hailed from Tangiers in Morocco. Aged 22 he left his native town bound for Mecca, visited Alexandria and Cairo, went up the Nile to Syene (now Aswan), from there to Syria and Palestine, crossed Arabia up to Mecca, turned towards East Africa and reached Mozambique, visited Asia Minor and Byzantium, southern Russia (up to the $55^\circ$ northern Lat.), Central Asia, India, the Malay peninsula and China, made extended sojourns and visited certain places repeatedly. After 24 years he returned to Tangiers. A second journey took him to Andalusia, a third to Northern Africa. With his travels lasting all in all 27 years, Ibn Baṭṭūṭa was, in the words of Richard Hennig327 “in fact the greatest world traveller in all Antiquity and Middle Ages.” Through Ibn Baṭṭūṭa’s gift for keen observation and his highly developed sense for matters of historical geography, anthropology and cultural history, his extensive travelogue became an invaluable document in the history of geography (cf. infra III, 8).

Historiography in the 8th/14th century brought forth numerous world chronicles, municipal and local histories, large-scale biographical dictionaries covering either the entire Islamic period or merely the present century, and various other writings; I shall confine myself to mentioning one world history and three encyclopaedias. The world history in question is the monumental Ġāmi‘ at-tawāriḥ by the above mentioned universal scholar Raṣīdīdān Faḍlallāh (d. 718/1318, infra, p. 157 ff.). It was begun in the year 700/1301 by commission of the Ḩārūn Gāzān as a history of the Mongols and the Turks; a few years later it was extended into a universal history according to the desire of ʿAlī b. Ṭabāṭabāʾī, the brother and successor of Gāzān, and was completed in 710/1311. The first volume deals with the history of Čengiz Ḥān and his successors in East and West Asia, as well as with the Turkish and Mongol tribes. The second volume deals at length with the history of the nations that came into contact with the Mongols. It begins with the pre-Islamic Iranian empires, followed by the history of the Muslim prophet and caliphs, Islamic dynasties in Persia, the

326 v. F. Sezgin, op. cit. vol. 10, pp. 200-210; vol. 12, No. 16a.
Oghuza, Turks, Chinese, Jews and Franks, and lastly India, with emphasis on Buddhism. The third volume devoted to geography is lost.

Rašidaddin’s book was of course not the first universal history produced in the Arabic-Islamic culture area on the history and culture of foreign nations, together with those in the Islamic world. It had numerous precursors like MuΩammad ad-dahab, Aḥbār az-zamān and Kitāb al-‘Āgā‘ib by ‘Ali b. al-Ḥusain al-Mas‘ūdī (d. 345/956 or 346),328 al-‘Unwān al-kāmil by Maḥbūb b. Qustānṭīn al-Manbīǧī (ca. 350/961),329 Tawāriḥ sinī mulūk al-arḍ wa-l-anbiyā’ by Hamza b. al-Ḥasan al-Islāfānī (d. before 360/970),330 al-Āṭār al-bāqiyā min al-qurūn al-ḥālīya (on the eras and festival calendars of the Greeks, Romans, Persians, the inhabitants of Soghdia, Ḥwārizm and Harrān, the Copts, other Christians and the Jews) and Tahqīq mā lī-l-Hind by Abu r-Raḥīm Muhammad b. Ahmad al-Birūnī (d. 440/1048)331 and many more written before, not to mention those after Rašidaddin.332 [62] However, in his work on the Mongols and nations that came in contact with them, Rašidaddin wanted to take a “new path” by “availing himself of the original historical sources of the respective nations themselves.”333 This he seems to have accomplished, at least in the Mongol history. The air of sobriety and objectivity pervading the whole work reminds us of al-Birūnī’s Chronicle (al-Āṭār al-bāqītayya) and his book on India (Tahqīq mā lī-l-Hind) mentioned above. The latter in particular has earned its author a unique position in cultural history, as the book not only leaned upon local sources, but was written on the basis of observations made by the author himself during a long stay in India and of insights gained in direct contact with the people.

The earliest large scale encyclopaedias also appeared in the first half of the 8th/14th century. The initial one is entitled Manāḥīǧ al-fikar wa-mabāḥīǧ al-‘ibār334 and was written by Ǧamālādīn Muḥammad b. Ibrāhīm al-Kutubi al-Watwāt (b. 632/1235, d. 718/1318).335 The work comprises the areas heaven and earth, animals and plants, and by its character testifies to the predominantly literary inclinations of its author. Inspired by this work, the Egyptian historian Ǧihābuddīn Aḥmad b. ‘Abdalwahhāb an-Nuwayrī (b. 677/1279, d. 732/1332) wrote his encyclopaedia Nihāyat al-arab fī funūn al-adab336, conceived in 30 volumes with the aim of collecting the knowledge expected of a cultivated secretary or government official. The inclusion of history as a separate, new topic offered the opportunity to cover all human affairs and achievements in the book; but an-Nuwayrī not only increased the number of topics (funūn) compared to his predecessor, he also made a new arrangement of the material: 1. heaven and earth, 2. man, 3. animals, 4. plants, 5. history. This encyclopaedia leads us to many traces of sources otherwise lost and it is one of the best textbooks on the history of that time.

The third encyclopaedia which appeared in this century is entitled Masālīk al-ṣbār fī mamālīk al-‘amsār and was written by Ǧihābuddīn Aḥmad b. Yaḥyā al-‘Umārī (b.

328 V. F. Sezgin, op. cit. vol. 1, pp. 322-326.
332 V. F. Sezgin, preface to the facsimile edition.
335 V. C. Brockelmann, op. cit. vol. 2, pp. 54-555; suppl. vol. 2, pp. 53-54; F. Sezgin, preface to the facsimile edition.
700/1301, d. 749/1349).\(^{337}\) It was composed between 741/1341 and 749/1349 when its author was head of the chancery in Damascus. It is possible that Ibn Faḍlallāh conceived the idea of creating his own encyclopaedia during his sojourn in Cairo, where he stayed until 740/1339. There he could have become acquainted with an-Nuwiari’s work which already enjoyed tremendous popularity. Yet the book of Ibn Faḍlallāh is different from that of his predecessor in its aim, structure, and content. Perhaps the Masālik al-ḥaṣār could be labelled an anthropogeographical encyclopaedia. Its title (“Routes toward Insight into the Capital Empires”) is also in accord with this. The first four of its twenty-seven volumes are devoted to geography. [63] All the other volumes deal with the intellectual achievements of humankind and its environment. Even though the entire work leaves the impression of a not yet fully fledged concept of an encyclopaedia, with its rich contents, it is one of the most significant literary achievements of the century, often going back to otherwise lost sources, and at the same time relating state of the art contemporary knowledge. In my opinion, the world map, the three sectional maps and the abundant text fragments from the Ma’mūn geography contained therein belong to the most important known documents in the history of geography and cartography.\(^{339}\)

After the encyclopaedias of the 8th/14th century, we now turn to a work that reflects the maturity of the period, being one of the greatest intellectual accomplishments of Arab-Islamic culture. It is the Muqaddima, the “Introduction” to history by ‘Abdarraṇī b. Muḥammad Ibn Ḥaldūn (b. 732/1332, d. 808/1406).\(^{339}\) The Muqaddima, written after the world chronicle al-‘Ibar wa-diwan al-mubtada’ wa-l-ḥabar dedicated to the Merinid ruler Abū Fāris ‘Abdal’azīz (reign. 768/1366-774/1372), was completed in the year 779/1377. It drew the attention of Arabists and non-Arabists after the two scholars Antoine-Isaac Silvestre de Sacy\(^{340}\) and Joseph von Hammer-Purgstall\(^{341}\) had drawn attention to its contents at the beginning of the 19th century. Particular interest was aroused in scholarly circles by Hammer-Purgstall referring to Ibn Ḥaldūn as the “Arabic Montesquieu”.\(^{342}\) In his work known as Prolegomena in the west, important fundamental ideas were discovered and commented upon with admiration: ideas concerning sociology, philosophy of history, economics, geography, anthropology, psychology and the history of sciences. Quite frequently Ibn Ḥaldūn is seen as the founder of sociology and the philosophy of history. Others find the basic problems of all branches of science addressed in his work. Regarding its treatment of the science of politics, the Muqaddima was compared to Il principe by Niccolò Machiavelli (d. 1527).\(^{343}\)

In the field of military technology, the development of firearms, initiated in the preceding


\(^{338}\) v. his article Ibn-Khaldoun, in: Biographie universelle (Michaud) vol. 21, Paris, shortly after 1811, pp. 268-270.

\(^{339}\) C. Brockelmann, op. cit. vol. 2, p. 141, suppl. vol. 2, pp. 175-176; for further bibliographical data v. the preface to the facsimile edition.


\(^{341}\) Born in Tunis, he held high offices in Fez, Granada, Tlemcen, Tunis and Cairo, where he died, v.


century, continued through the 8th/14th century. In an anonymous book on the technology of warfare, which is kept in the Asiatic Museum (Institut Narodov Azii) in Petersburg and probably belongs to the first half of the 8th/14th century, a combined thrusting weapon and hand gun is described which consists of a hollowed out lance that also serves for shooting a missile driven by the force of gunpowder. [64] It seems that this type of hand gun reached Europe at the turn of the 8th/14th to the 9th/15th century (infra V, 133). Besides this, in the same St. Petersburg manuscript we find the illustration of a firearm which appears to be a kind of mortar; however, the illustration does not match the description in the text. It is possible that the illustration depicts yet another mortar-like weapon, different from the one in the description (ibid).

The earliest mention of a steel crossbow known so far dates back to the first half of the 8th/14th c. as well (infra V, 96). In all probability, Europe became acquainted with this as early as at the turn of the 8th/14th to the 9th/15th century. The earliest reference to the use of steel crossbows in Europe dates from the year 1435.345

The 9th/15th century

According to the provisional state of our knowledge, scientific activities were still intact in all fields and throughout the Islamic world in the 9th/15th century. The new cultural centres emerging in the Seljuk dominions founded since the 6th/12th century in Anatolia and in the Ottoman empire which began to expand from the beginning of the 8th/14th century contributed substantially to this. Of the numerous works surviving from that century and kept in libraries as manuscripts, only a small fraction has been published yet and even fewer have been studied. In this connection, we may point to the outstanding activities in the field of astronomy and mathematics during the first half of the century in Transoxania which are connected with the name of the statesman Ulugh Beg Muhammad Türgay (b. 796/1394, d. 853/1449). He turned Samarqand into what his grandfather Timur had envisioned, i.e. the centre of Islamic civilisation of his times.346 This prince who was filled with enthusiasm for the sciences in his youth had received a sound education in theology, history, poetry and other subjects; long before his ascent to power he invited many famous scholars to Samarqand, including Gıyâladdîn Ğamšid b. Mas'ûd al-Kâšî (d. 832/1429) and Qâdîzâde Rûmî (d. ca. 840/1436). Of the institutions which he founded there, the most important was without doubt the monumental observatory—inspired by its forerunner in Marâğa—where he himself worked alongside the scholars mentioned above. The younger scholar ʿAlâʾaddîn ‘Ali b. Muḥammad al-Qūšgī (d. 879/1474) also contributed to the construction and the further development of the observatory in Samarqand. Judged by the extant remains, the radius of the scale, built according to the principle of the Faḥrī sextant in Rayy (4th/10th century, infra II, 25), measured about 30 m. Most of the results of the observations made at the observatory347 were incorporated into the book of tables, Zîg-i Sulṭānî, composed by Ulugh Beg himself. In Europe John Graves draw attention to this fact as early as in the middle of the 17th century.348

344 Current accession number C 686 with the title al-Mahzûn fi ḡanîl al-junûn (infra V, 100).
Amongst the noteworthy astronomical achievements of this century are also the extensive tables by ḡiātaḍdiṁ al-kaṣī entitled zig-i ḫaqānī, which the author compiled at Herat in 816/1413, even before the foundation of the Samarkand observatory. [65] Its geographical table shows a remarkable increase in the coordinates from Transoxania.

In the history of the development of astronomical instruments al-kaṣī occupies quite an important position as well. In his treatise on astronomical instruments he deals primarily with those of the observatory in Marāḡa (infra II, 38 ff.; besides this, we should also mention a separate work entitled Nuzhat al-ḥadāʾiq in which he describes the two instruments which he calls tabaq al-manāṭiq and lauh-i ittiṣālāt. The former to our knowledge represents the ultimate stage in the development of an instrument called zig-i ḥafāʾiḥ in the first half of the 4th/10th century by Abū Ǧaʿfar al-hāzin; this instrument was meant to determine mechanically the true position of a planet on the ecliptic at any given time, largely without the use of astronomical tables (supra p. 20). As mentioned above the original version of this instrument had found its way to Muslim Spain rather early on. The treatises written on it by ʿasbaḏ b. muḥammad Ibn as-Samḥ al-ğarnātī (d. 426/1035) and Abu ṣ-ṣalt umayya b. ʿabdallʿaziz al-Andalusī (d. 528/1134), as well as the description of a substantially improved version of the instrument by ʿibrāḥīm b. yahyā ʿaz-zaqālī (2nd half 5th/11th c.), reached the non-Spanish Occident in the second half of the 13th century at the latest through their translation into Castilian in the Libros del saber de astronomía. The most advanced feature of al-kaṣī’s instrument is his central alidade with a graduated parallel ruler with which the essential operations can be carried out by projection of simple markings, e.g. by placing it through the centre of a given deferent in order to find the true centre of the epicycle on the deferent at a given time. [65] From the fact that al-kaṣī’s instrument shows a close similarity to the equatoria of G. Marchioni (written in 1310) and to the one ascribed to Geoffrey Chaucer (d. ca. 1400), I conclude that the latter two must have become acquainted with an older eastern specimen which was the model for al-kaṣī’s instrument as well. As far as the second instrument, lauh-i ittiṣālāt, the “conjunction plate,” [353] is concerned, it was meant to serve for the mechanical computation of the expected days of conjunction of two planets on the basis of the differences, calculated beforehand, between the longitudes of each and the known differences between the distances traversed daily by the planets on their respective orbits. This type of computation device (made of wood or brass) is otherwise unknown.

In theoretical astronomy we shall also mention the interesting model for the planet Mercury developed by the above-mentioned ʿAlāʾaddin ʿalī al-Qūṣī (d. 879/1474) which came to light just a few years ago. [354]

[66] In the field of mathematics, research has revealed many important achievements in the

works of Ğiyātaddin al-Kāši analyzed so far; in many cases they represent the ultimate stage of development in the Arabic-Islamic culture and found their way to Europe several centuries later or had to be discovered again. Only a few examples shall be mentioned here.

In the history of algebra, al-Kāši holds a special position through his in-depth study of equations of the fourth order. From a brief discussion of the subject in his “Key to Mathematics”, Miṣfāḥ al-ḥisāb,355 we learn that he knew 70 types (or 65)356 of equations of the fourth degree and that he planned to treat them in a separate volume. It is presently unknown whether he actually found the time to do so or, if he did, whether the work is extant.

In this connection we may mention that in his Miṣfāḥ al-ḥisāb al-Kāši gave some interesting examples of his treatment of the rules of summation of arithmetical and geometrical series of higher degrees. His summation of the series of the fourth degree reminds us of the achievement by his predecessor Ibn al-Haštam four hundred years earlier. However, al-Kāši arrived at the result in his own masterly way.357

Historians of mathematics in the later part of the 19th century were surprised when Franz Woepcke358 published the result of his research to the effect that Ğiyātaddin al-Kāši had used a very accurate method of approximation while calculating \( \sin 1^\circ \), the like of which the Occident only came to know from François Viète (1540-1603).359

For the calculation of the daily movements of the planets al-Kāši used a method of iteration. Although we already know the application of the iteration method from earlier scholars in connection with the computation of the lunar parallax, it occurs for the first time as a bona fide mathematical problem in al-Kāši’s work.360

Al-Kāši’s outstanding result in the measurement of the circle has been known to the historiography of mathematics for fifty years. He criticises the results of his predecessors Archimedes, Abu l-Wafā’ and al-Bīrūnī and their methods. He himself calculates the ratio circumference and diameter of a circle with the help of an inscribed and circumscribed polygon each with \( \frac{3\cdot 2^{28}}{800} = 335 \frac{168}{83} \) sides and thus arrives at \( \pi \approx 3,14159265358979325 \). Prior to Paul Luckey361 making known this achievement, Johannes Tropfke362 had stated that only with F. Viète and Adriaan van Roomen (1561-1615) had a “new, lustrous era” begun for the measurement of the circle “in which through ever more precise calculations the approximation to the true value had been improved to an unexpected extent”. With a method involving polygon calculation, Viète [67] established the value for \( \pi \) up to nine decimal points, von Roomen up to fifteen. Al-Kāši in his days had already come up to seventeen decimal points.

In connection with the calculation of chords, al-Kāši arrived at the trigonometric formula363

\[ \tan \frac{x}{2} = \frac{\sin x}{\frac{1 + \cos x}{2}} \]


359 v. F. Sezgin, op. cit. vol. 5, p. 63.


363 v. F. Luckey, Der Lehrbrief über den Kreisumfang,
which is known in the West under the name of Johann Heinrich Lambert (1728-1777):

$$\sin \left( 45^\circ + \frac{\theta}{2} \right) \approx \sqrt{\frac{1 + \sin \theta}{2}}.$$

Al-Kâšî also holds a distinguished position in the history of decimal fractions. Here the Arabic mathematician al-Uqlîdisî (4th/10th c.) was his eminent predecessor (supra p. 211). Yet al-Kâšî was the first to treat the subject systematically. To our knowledge, decimal fractions only came to be commonly used in the Islamic world after al-Kâšî. In Europe, decimal fractions were introduced by the Jewish mathematician Immanuel Bonfils (mid 14th c.). How he got into this position has yet to be explained. However, according to Juschkewitsch, his brief sketch was “utterly insignificant compared with al-Kâšî’s treatment of decimal fractions.” There can hardly be any doubt that al-Kâšî’s algorithm of decimal fractions must soon have reached Asia Minor and Constantinople through his disciples and successors or even through Byzantine travellers to Persia. In this connection we shall mention a surviving 15th century Byzantine arithmetic book whose anonymous author knows how to reckon with decimal fractions and mentions that the Turks ruling the former Byzantine do-

op. cit. p. 49 (reprint p. 283); F. Sezgin, op. cit. vol. 5, p. 66.


365 V. S. Gandz, The invention of the decimal fractions and the application of the exponential calculus by Immanuel Bonfils of Tarascon (c. 1350), in: Isis (Bruges) 25/1936/16-45; P. Luckey, Die Rechenkunst bei Šamšîd b. Maṣ'ûd al-Kâšî, op. cit. p. 120-125 (reprint op. cit. pp. 202-207); F. Sezgin, op. cit. vol. 5, pp. 67-68.


minions commonly used such operations. The first systematic treatment of decimal fractions in Europe appeared in the small volume De Thiende (“The Tenth Part”), written in Flemish by the Dutch merchant, mathematician and engineer Simon Stevin (1548-1620). 368

Regarding al-Kâšî’s important achievements in the field of mathematics, we shall finally mention the chapter on regular and semi-regular bodies in his “Key to Mathematics”. Of course, al-Kâšî had precursors in dealing with this matter; however, the complex calculations and constructions he presents with commanding skill, calculating the volumes of curvilinear circumscribed bodies, slanting cylinders and cones as well as other irregular hollow bodies, pointed arches, vaults, domes and stalactites, bear witness to the comprehensive expertise reached in Arabic-Islamic mathematics with al-Kâšî in the first half of the 9th/15th century. 369

From the field of mathematics of this century we shall further mention that algebraic symbolism, developed in the western part [68] of the Islamic world from the 7th/13th century, reached a climax in the Kâşî al-mahjûb min ‘īlm al-ǧubâr by Abu l-Ḥasan ‘Alî b. Muhammad al-Qalaṣādî (d. 891/1486). 370 “The first power, the square and the third power of an unknown are marked in the equations by the first letters of the words šai’, māl and kaʾb and these characters too appear above the co-efficient.” 371

The progress made during the 9th/15th century in the field of cartography in the Arabic-
Islamic area appears to have been very considerable. The most significant development with epochal consequences for the history of the world took place regarding the shape of the southern part of Africa, the depiction of which got very close to reality. In the Arabic-Islamic world the conviction that the African continent was circumnavigable in the south—contrary to the notion of the Indian Ocean as a land-locked sea held by Marinus and Ptolemy—can be traced back to the appearance of the world map by the Ma'mûn geographers in the first quarter of the 3rd/9th century. From a remarkable report by the historian and geographer Ahmad b. Abî Ya'qûb b. Ga'far al-Ya'qûbî from the last third of the 3rd/9th century, we learn that merchant vessels built in Ubulla on the Tigris for the China trade, anchored in the Maghribi seaport Másâs (south of Agadir on the Atlantic coast) near the Bahlûl mosque. The Ma'mûn geographers’ depiction of Africa was based on the rough idea of a land mass, circumnavigable in the south and stretching eastwards to 160°. The mathematical survey of the large continent commenced some centuries later. The three oldest extant charts of Africa after the Ma'mûn map are the ones by al-Kindî and as-Sarâhî (3rd/9th c.), that by a 4th/10th or 5th/11th century anonymous, and the one by al-Idrîsî (ca. 548/1154). These maps are all either corrupt or crude reproductions of the map drawn for al-Ma'mûn. On the other hand, the depiction of Africa in the surviving sketchy world map by Našîraddîn at-Ţûsî (d. 672/1274, supra p. 47) turns out to be a considerable advance. This, in turn, is connected with the rendition of Africa on the type of Chinese world map which emerged in the early 14th century stimulated by

the terrestrial globe sent to China from Marâqa in the year 1267, or other contemporary Arabic-Islamic maps. The crucial aspect in the depiction of Africa on these Chinese maps is the triangular shape of the southern part of the continent (supra p. 47), although the original dimensions of the map have suffered through the negligence of the copyists. In the depiction of the peninsular shape of Africa on European world maps from Brunetto Latini (ca. 1265) to Fra Mauro (1459) there are still no traces of mathematical-astronomical methods. Of course that does not mean to say that no attempts had been made in the Islamic world at that time to determine the coordinates of places in Africa. In the tradition of the work begun in the early 3rd/9th century, extending in scope and gradually gathering momentum, measurements according to the rules of mathematical geography were taken from time to time. Yet it took time until the results would show themselves in maps. For a realistic depiction of the configuration [69] of an entire continent and beyond, continuous and organised efforts by generations would have been required.

Consequently it was considered quite a milestone in the history of geography and cartography when a perfect or near-perfect cartographic depiction of the configuration of Africa and South Asia including India was brought into circulation in Europe shortly after Vasco da Gama’s return from his first expedition to India. Ignorance concerning the high level of mathematical geography, cartography and navigation based on scientific methods in the Arabic-Islamic world made it more difficult to identify the true originators of those maps. The accepted explanation was to the effect that those maps had been drawn up by Portuguese map-makers using data collected and provided by Vasco da Gama; this explanation, on the one hand, betrays a complete lack of insight regarding the circumstances under which an accurate map of such a large part of the

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373 v. F. Sezgin, op. cit. vol. 10, pp. 136-137; vol. 12, p. 11.
374 v. ibid, vol. 10, p. 134; vol. 12, p. 12.
377 v. ibid, vol. 11, pp. 354 ff.
Earth’s surface alone could have been compiled, and, on the other hand, it shows that a wealth of historical evidence contradicting such an assumption was ignored. The disregard for cartographic reality may be exemplified by the case of the so called Cantino map, considered to be the first one drawn after Vasco da Gama’s return from his first expedition, probably around 1502. A comparison of this world map with a modern one shows that the lines of the equator and of the two tropics are drawn accurately across Africa, the Arabian peninsula and India. The west-eastern extension of Africa at the equator and the distance between the equator and the Cape of Good Hope are almost the same on the Cantino map and the modern one (modern values are $33^\circ 30'$ and $34^\circ 30'$ respectively), while the distance between the east coast of Africa and the meridian of Cape Comorin (South India) at the equatorial line is about half a degree larger on the Cantino map than the modern value ($35^\circ$). Thus regarding the dimensions of the southern part of Africa and in the distance between the east coast of Africa and the southern-most point of the Indian peninsula, this world map displays an accuracy in longitude and latitude that was not matched by European maps of Europe and Asia prior to the 19th, in some respects even the 20th century. Hence, by the accuracy of the Cantino map, we may assume that this map offers clues leading to a model which was made locally and based on a sufficiently long-term survey in the area, collecting all the coordinates and distances required. It is hardly conceivable how Vasco da Gama, who had to reach southwest India on an established and fixed route and who had to return in the shortest possible time along that same route, could have procured the data required for the map, not to mention that this was neither his aim, nor his order. The voyages were of a mercantile and political nature. For the sake of justice it should be said that the Portuguese in those days did not claim to have created the prerequisites for making these maps themselves. Their task and achievement consisted in bringing as many maps drawn in foreign countries as possible to Portugal, where map-makers translated them into Portuguese, copied them and presented them according to their own understanding and taste. Most of the early Portuguese seafarers in the Indian Ocean make no secret of having seen maps with Arabic or other Muslim sailors quite often, or of having procured such maps. Amongst the reports known to us, there is even a detailed report by [70] Vasco da Gama himself about his first encounter with a Muslim navigator on the east coast of Africa. Da Gama relates how he saw maps with longitudes and latitudes in the hands of his Arabic colleague, which the latter used on his voyages. He was one of the navigators who piloted Vasco da Gama on the direct sea route to Calicut, on the west coast of India.

Other reports state that as early as in the first half of the 15th century maps of the Indian Ocean and of Africa, circumnavigable in the south, reached Portugal. Thus the sea route to India must have already been known to the Portuguese before they, encouraged by such maps, endeavoured their expeditions, incorrectly referred to as “voyages of discovery”.

With this brief exposition I intend to acquaint the reader with the conclusion I reached in the 11th volume of my Geschichte des arabischen Schrifttums, viz. that the stage of cartographic depiction of Africa and the Indian Ocean reached just before the Portuguese expeditions was largely accurate and thus constitutes one of the most significant achievements of the Arabic-Islamic world in the 9th/15th century. The merit of the Portuguese consists in them having rec-

381 v. F. Sezgin, op. cit. vol. 11, pp. 358-362
382 v. ibid, vol. 11, pp. 323-444.
ognised the importance of those maps, in collecting them and taking them to Portugal; thus they implemented their wide circulation in European languages and ultimately gave the impetus for an upsurge in cartographic activities in Europe. Otherwise, I could not see since when and through whose mediation those maps could have reached Europe, no longer just sporadically, but on a regular basis.

Concluding this topic, I would like to mention what I consider the greatest known cartographic achievement of the Arabic-Islamic world. We owe its discovery and preservation to the Portuguese. It is the “Javanese” atlas that fell into the hands of the Portuguese shortly after the conquest of Malacca in 1511 and was sent to King Emanuel I (d. 1521) by the conqueror Alfonso de Albuquerque. In his accompanying letter to the king Alfonso writes: “I am sending you a part of the copy of a large map made by a Javanese pilot representing the Cape of Good Hope, Portugal, the country of Brazil, the Red Sea, the Persian Sea, the Spice Islands (the Moluccas), the sailing routes with the direct route to China and Formosa which the ships take along with the interior [of these countries] which adjoin one other. It seems to me that this is the most beautiful thing which I have ever seen. Your Majesty will be greatly pleased to see it. The place names are in Javanese characters, I had a Javanese who can read and write. I am sending Your Majesty that part, which Francisco Rodrigues copied from the original, in which Your Majesty will be able to see for yourself where the Chinese and the inhabitants of Formosa come from, what route your ships need to take to reach the islands of cloves, where the goldmines are, the islands of Java and Banda, the island of nutmegs and mace, the empire of Siam, the Cape of the Chinese, which they [71] sail round and where they turn round and do not go beyond. The original was lost with the Frol de la Mar (when it was shipwrecked). I have discussed the content of this map together with the pilot and Pero Dalpoem so that I might describe it to Your Majesty clearly. This map is very precise and well known because it is used in navigation. On the archipelago of the islands known as ‘Selat’ is missing (between Malacca and Java)”.

Modern cartography-history has failed to give a proper assessment of these maps and the question of their provenance, as it knows nothing about the mathematical navigation which had provided crucial impulses for the cartography of the Indian Ocean in the course of the preceding development. With their longitudinal and latitudinal scales and near perfect configurations, the twenty-six extant parts of the atlas bear witness to a long tradition of cartography based on mathematical-astronomical principles. The atlas offers the earliest largely correct depictions known so far, of the Bay of Bengal, the Straights of Malacca and of the southern Chinese Ocean from Java across the Moluccas down to Canton. The island of Madagascar appears here for the first time on a map. Its delineation is so good that it was improved upon only by cartographers of the 19th and the first half of the 20th century. The fact that the atlas even includes the north-eastern coastline of South America—mentioned also by Alfonso de Albuquerque, thus ruling out the option that it was a Portuguese addition—implies that the endeavour to advance the inherited cartographic world view according to the latest knowledge

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384 v. F. Sezgin, op. cit. vol. 11, pp. 327-328
385 v. ibid, vol. 11, pp. 426-433.
386 v. ibid, vol. 11, p. 441.
was still alive in the Arabic-Islamic area in the first decade of the 10th/16th century.

Such an advanced cartographic survey of the Indian Ocean and the African continent would have been impossible if cartography had not constantly benefited from the association with and the aid of scientific navigation. Today we are in the privileged position of knowing the specific nature of this navigation tolerably well. After a long evolution, it reached its climax in the Indian Ocean region during the second half of the 9th/15th century and in the first quarter of the 10th/16th century.

Navigation on the sea routes between Arabia and China dates back several millennia; the oldest preserved written documents dealing with this navigation date from the second half of the 9th/15th century. Even though is known that there was a body of writings concerning nautical rules and knowledge about routes, sea-ports and distances in the Indian Ocean at a much earlier time, unfortunately these writings were considered obsolete and got lost when the works of the two greatest exponents of navigation in the second half of the 9th/15th century and the first quarter of the 10th/16th century appeared, representing a higher development in the field.

The first of those two was Šibābaddin Ahmad Ibn Māgid b. Muḥammad from Gūlfār in the province of ‘Umnān. A number of his works are extant and these also reflect a certain development in the knowledge and abilities of their author in the course of his life. According to Ibn Māgid, navigation, which he calls ‘ilm al-bahr, is a “theoretical and empirical science, as opposed to a mere paper tradition” (îlm ‘aqī̄̂ li taqrībi la naqīli). He divides navigators into three groups. The first are the simple pilots whose voyages turns out sometimes well, [72] sometimes not, whose answers are sometimes right and sometimes wrong. These mariners do not deserve the title mu’allim (“master”, sing.). The members of the second category, the average ma’ālim (“masters”, pl.) are known for the range of their knowledge. They are proficient, completely at home with the routes of the localities to which they sail, but once they die they are forgotten. The third class of navigators is the highest. Those who belong to it are widely known, command all the operations performed at sea and are scholars “writing treatises” from which one can benefit during their life time and also afterwards.

Ibn Māgid also mentions the regulations a captain has to observe during his voyage and the moral principles expected of him. He is conscious that an important position is assigned to his own person in the history of navigation and that his achievement shall not be without impact upon subsequent generations. (“There will come a time after us when it shall be possible to judge which position is due to each of us in our profession.”)

Ibn Māgid is convinced that he himself had advanced his field, notwithstanding his earlier works containing points that require correction. Interestingly he calls the material from his earlier writings he no longer wishes to uphold—in his present higher level of knowledge—“revoked” (mansūh) and that what replaces them “revoking” (nāsih), thus using terms usually employed in connection with the revelation of the Qur’ān.

From Ibn Māgid’s extant works we learn unambiguously that he was indeed not merely a theorist, but had himself been a mariner for many years, sailing between Arabia, India and South East Asia. His books create the impression—perhaps not in quite as systematic a fashion as one might desire—that he represents a

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388 Ibn Māgid, Kitāb al-Fawā’īd, op. cit. p. 171; F. Sezgin, op. cit. vol. 11, p. 177.
389 Ibn Māgid, Kitāb al-Fawā’īd, op. cit. p. 171; F. Sezgin, op. cit. vol. 11, pp. 177-178.
navigation based on the orientation to the North Star and to a number of other fixed stars (that rise and set on the horizon within a distance of approximately 11°15' from each other) and on the use of the compass. In his books he records the latitudes of hundreds of localities in the Indian Ocean area with compass bearings, but we find little information on how measurements of distances were taken. It seems, here and elsewhere, that Ibn Māgid expects his reader to have a certain expertise. In one passage of his extensive work al-Fawā’id he discloses that some inventions in the field of nautical science are his own achievements, including an improvement of the compass where the magnetic needle itself is put on the compass, that is to say, it moves on top of the cardboard disc inscribed with the thirty-two bearing marks, rather than being fixed underneath.

In his surviving books Ibn Māgid comes across as an accomplished, self-confident navigator with a thorough knowledge of astronomy and well versed in many other areas of knowledge of his times. His material reveals that we are here dealing with a mathematically surveyed Indian Ocean and with highly developed methods of navigation. Yet we learn how all this was accomplished and what the actual workings of this navigation were not so much from Ibn Māgid as from his younger colleague, Sulaimān al-Mahri. Adhering to the chronological principle which we follow here, Sulaimān al-Mahri’s more lucid [73] treatment of the subject shall be discussed in the context of selected topics of the 10th/16th century.

From the 9th/15th century we shall also mention two encyclopaedias which reflect the high standards of that time. One of them is the well known encyclopaedia of the art of writing and knowledge required for secretaries, written by the Egyptian secretary of state, Shihābuddin Ahmad b. ‘Ali al-Qalqašandi (b. 756/1355, d. 821/1418) entitled Šubh al-a’šā fi sinā’at al-inšā‘; it is divided into ten main sections comprising fourteen volumes.\(^{*}392\) Completed in 814/1412, this encyclopaedia, rich in content, systematically arranged, and with properly referenced sources can be regarded as one of the most impressive verifications of the cultural flowering across all areas of life in Arabic-Islamic society reached after a development of about eight hundred years.

The second important encyclopaedia from this century is a work which has so far remained largely unknown, the Kašt al-bayān ‘an šifāt al-hayawān by the versatile Alexandrian scholar Muḥammad b. Muḥammad b. ‘Ali al-‘Auí\(^{*}393\) (b. 818/1415, d. 906/1501). This work, surviving in an autograph of sixty-two volumes,\(^{*}394\) is possibly the earliest encyclopaedic reference book to be arranged alphabetically, providing information on all fields of interest. Volume sixty-two breaks off with the letter qāf (i.e. only about two thirds were finished). The author cites the names of his sources, many of which are lost today. It is said they amount to three thousand titles.


\(^{*}394\) Vols. 2-62 are preserved in the collection Feyzullah (No. 1687-1745, II Halk Kütüphanesi) in Istanbul, vol. 1 in the collection Süleymaniye (No. 873, Süleymaniye Kütüphanesi), a late copy of this is in Paris, Bibliothèque nationale, ar. 4825.
Following this colossal encyclopaedia we should mention another work which reflects the pronounced interest of that time in cultural history and the vision of its author with regard to history. A little known scholar from Damascus, ‘Abdalqadir b. Muhammad an-Nu’aimi395 (d. 927/1521), took it upon him to write the history of the schools and universities of his homeland from around the 5th/11th to the 10th/16th centuries. Surviving in two volumes under the title *ad-Daris fi ta’rīh al-madāris,*396 the work deals with the mosques, monasteries and tombs attached to the schools and is apparently an extract from the author’s *Tanbih at-tālib wa-īrādād ad-dāris fimā fi Dimaq min al-ğawāmi’ wa-l-madāris.* It informs, inter alia, “about the career and works of scholars, about their peculiarities and attire, about quarrels ended by intervention of the Sultan, about edicts (tawāqi‘) from Egypt through which teachers were transferred and textbooks replaced. Some teachers had only a part-time position (nisf tadrīs).*397* The importance of this book becomes evident when one tries to find its like in the Europe of that time.

**[74] The 10th/16th Century**

The great observatory founded in Istanbul between 1575 and 1580 under the Ottoman sovereign Murad III is one of the achievements of the 10th/16th century to be mentioned in this overview. The idea was suggested to the Sultan by the versatile scholar Taqiyyaddin Muhammad b. Ma'ruf ar-Rassad. With a “new kind of observation” (raṣad ḡadid) using newly built instruments of large dimensions, the latter intended to collect substantially improved results. The surviving Turkish book on the observatory and its instruments contains the description and illustrations of eight observational devices of hitherto unknown proportions. It was probably first dictated in Arabic by Taqiyyaddin (who had only settled in Istanbul in the 1550s after sojourns in Damascus and Cairo). Two of the instruments seem to have been devised by Taqiyyaddin himself, the other six already figure in the instruments book of the observatory at Maraga built three hundred years earlier (supra p. 41 f.). One may assume that news about the Istanbul observatory soon reached Europe and that the great astronomer Tycho Brahe (1546-1601) also heard about it. At any rate, the similarity between two of the instruments in Taqiyyaddin and Tycho Brahe (viz. the instrument for measuring the distances between celestial bodies and the wooden quadrant, infra II, 64, 68) create this impression. Moreover, Stefan Gerlach, pastor of the German emperor’s ambassador in Istanbul, reports at length on the foundation of the observatory in his ‘Turkish Diary’ (*Türkisches Tagebuch*) entry 13th November 1577.398 Salomon Schweigger, another clergyman in the entourage of a western ambassador, stayed in Istanbul from 1st January 1578 to 3rd March 1581 and wrote about the event with a strong bias, which itself is quite interesting for the history of culture and science. In his travelogue he calls Taqiyyaddin “a wretched blockhead” who “some years ago had been held prisoner in Rome, where he learned much about the arts of a mathematician whose servant he was and thus became such a celestial artist and planetary jester.” Allegedly, he even had Arabic translations of works by Ptolemy, Euclid, Proclus and “other writings by famous astronomers” secretly explained to him by a Jew.399 It goes without saying that these assertions are not correct and that

Taqiyyaddin’s stay in Rome is pure fiction. Yet the acerbity with which the spirit of antagonism towards the Arab-Islamic area makes its appearance here, draws our attention; a tendency that had already begun in the 13th century but now, from the second part of the 16th century, was combined with a feeling of superiority in the sciences, which, even though perhaps not quite justified yet, shortly afterwards was to become real.

The observatory in Istanbul was established in succession to the two precursors in Marāgā and Samarqand, whose fame had spread beyond the Islamic world. After many years of work as an astronomer and physicist, its founder, Taqiyyaddin, moved to Istanbul in the 1550s to place his knowledge and abilities in the service of Murād III. The latter was intelligent enough to grant the request and have the costly observatory built, [75] but he was not intelligent enough to appreciate its true merits. Thus he could be persuaded by fanatical advisers and the adversaries of Taqiyyaddin to demolish the observatory as an alleged instrument of astrology with a corrupting influence on the state only a few years after its foundation.

Taqiyyaddin was possibly the first astronomer to introduce time as a distinct parameter in his observations. For this purpose he built a large astronomical clock (bingām raṣādi) as an addition to the instruments of the observatory (infra III, 117). Taqiyyaddin enjoyed considerable fame in the Ottoman Empire not only as a rāṣid (observing astronomer) but also as a muhandis (engineer). From his two extant treatises on pneumatic constructions and clocks he indeed emerges as an eminent physicist and technician. In his book on pneumatics, Taqiyyaddin describes a number of machines and devices that reveal an already well-developed level of technology. The precise descriptions enabled us to reconstruct several devices without great difficulty; of these, we may first of all mention an automatic pump with six piston-like plungers powered by the current of a river, transferred through a waterwheel onto a camshaft. The cams in turn move six levers which drive the plungers. This type of waterwork with six plungers appears for the first time in Taqiyyaddin’s book. About 350 years earlier ar-Razzāz al-Gazari (supra p. 37) had already known waterworks with two plungers.

Thus it is possible that there was an intermediate stage of development in the period between the two authors. In this respect it is interesting that Taqiyyaddin praises a work by ‘Ali al-Qūṣī (d. 879/1474) on pneumatics and mentioned as one of his sources. At the present time it is not known whether the concept of waterworks with multiple pistons as described shortly afterwards in Europe by Georgius Agricola(e) (1494–1555) and Agostino Ramelli(3) (1531–1600?) was connected with the Arab-Islamic world or whether it developed independently.

Taqiyyaddin also describes the two types of mechanised turnspits for roasting meat most common in his time, one of which is turned by steam and the other by hot air.

The description of the second device resembles a turnspit-construction sketched by Leonardo da Vinci which was also intended to be powered by hot air (infra V, 39). Moreover, Taqiyyaddin describes numerous devices func-

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401 In his al-Kawkāb ad-durriyya fi wa’d al-bingāmūt ad-durriyya, ed. Sevim Tekeli in önci asırda Osmanlılarda saat ve Takiyyuddin’in “Mekanik saat konstrüksiyona dair en parlaq yıldızlar” adlı eseri, Ankara 1966, pp. 46, 144, 222.


tioning by transmission of force with cogwheels. They must have been very common in his days. He refers to one of them as his own invention.

In the field of mathematical geography, in the 10th/16th century we encounter tables of coordinates and maps that display an increase in the mathematically surveyed parts of the oikoumene and an enhanced cartographic depiction. It is of course impossible to say in each case whether the progress had really only been achieved by the 16th century or whether it dates back to the preceding one. One of the most significant extant documents of the high standard reached in the cartography [76] and navigation of the Mediterranean is the Kitāb-i Bahriye of the Ottoman seafarer Piri Re’is (ca. 1465-1554), who defines the term bahriye as the “science of the oceans and the technology employed by mariners”. This monumental work testifies to the author’s great literary maturity. It is his consistently pursued aim to enable an optimized voyage in the Mediterranean on the basis of detailed physico-geological, archeological and meteorological data. Besides the enormous amount of data collected for that purpose, Piri Re’is furnished his book with more than 200 charts of islands, harbours and some coastal regions of the Mediterranean of astounding quality which, undoubtedly, can only be understood as the result of a long-term development. Unfortunately, recent researchers have so far paid less attention to the contents and the detailed maps of the book than to the fragments of his world map. This he himself calls the most comprehensive world map in circulation at the time. To our knowledge it is the last attempt made in the Arab-Islamic culture area to create an up-to-date world map on the basis of all accessible sources.405

Another Ottoman document from the time of the second edition of Piri Re’is’s work testifies indirectly to a rather highly developed and once again extended world map. The “time keeper” (muwaqqit) of the Selimiye mosque in Istanbul, Muşṭafâ b. ‘Ali al-Qustanṭini al-Muwaqqit (d. 979/1572), when still a young man, dedicated his booklet *İlaml am-i ibâd fi d’lám al-bîlâd* to Sultan Süleyman (r. 926/1520-974/1566) in the year 931/1525; in it he gives the longitudes and latitudes of 100 localities and their rectilinear distances from Istanbul in miles. Those places are more or less well known cities in the northern hemisphere, located between the west coast of Africa and the east coast of China. What makes this heterogeneous compilation important is, firstly, that longitudes in it are given consistently according to the prime meridian (shifted by 17°30’ to the west of the Canary Islands in the Atlantic Ocean), hence the significantly revised longitudes of the world map must have been commonly known in the early Ottoman empire; secondly, that it documents how the part of the world mathematically surveyed in the Arab-Islamic region was further extended at that time. The coordinates recorded in this book show that the main points of the configuration of the Mediterranean, the Black Sea and Anatolia almost match the modern values. Moreover, they corroborate contemporary values known to us from other sources.407 Yet the greatest importance of this book regarding the history of cartography lies, in my opinion, in the fact that it includes the earliest known coordinates of the northern Siberian fortress Armayat ar-Rüs, later to be known as Tobolsk. The longitude given is quite close to the actual value, while the latitude deviates from the modern value by only 15’.408 This, of course, is not only a confirmation of our assumption that the mathematical survey of northern Asia had be-

406 Regarding the manuscripts, v. ibid, vol. 1, pp. 162-163.
408 v. ibid, vol. 10, pp. 188, 191.
gun in the Arab-Islamic world relatively early on, namely around the 7th/13th century, but it is also the earliest evidence so far that Ottoman geographers and cartographers must have possessed a fairly accurate cartographic depiction of these areas, certainly by the first quarter of the 10th/16th century. What’s more, this document offers us the first clue as to where exactly a 16th century European cartographer like Gerard Mercator could have acquired his latitude for the city of Tobolsk (58°), a question which has so far apparently never been posed in the history of cartography.

From the descriptive branch of geography we can also cite an interesting example demonstrating that science in the Islamic world was still at a comparatively high level in the 10th/16th century. The example is provided by the scholar al-Hasan b. Muhammad al-Wazzàn (b. around 888/1483), known in Europe as Leo Africanus. Born in Granada, he grew up and received his education in Fās (Fez, now Morocco); in diplomatic service he travelled to various Islamic countries, particularly of northern Africa, and, as a writer, developed an interest in geography and local cultures. On the way back from Istanbul he fell into the hands of Sicilian corsairs and was sold first to Naples and then to Rome where he was baptised by Pope Leo X, after the latter’s own name, Giovanni Leo on January 6, 1520. During his stay in Italy he learned Italian and taught Arabic. In 935/1529 he returned to Tunis where he died as a Muslim. In Rome and Bologna he had continued his literary work. Besides a description of Africa, he compiled a work comprising thirty biographies of north-African scholars. His description of Africa in Italian was completed in 1526, the sixth year of his captivity. The book consists of nine chapters. The first deals with the general physical and climatic characteristics of Africa and with its inhabitants. The second deals with the region of Marrākuš (Marrakesh) with its cities and mountains, the third with Fās, the fourth with Tilimsān (Tlemcen), the fifth with Tunisia, the sixth with Libya, the seventh with the Sudan, the eighth with Egypt and the ninth with the rivers, natural resources, the flora and fauna of Africa. All in all some 400 localities are introduced. The author remarks that he had relied primarily on his own observations but, where he could not provide any information himself, had taken pains to obtain detailed reports from reliable and knowledgeable people.

Next to al-Idrīsī’s Nuzhat al-muṣṭāq, Leo Africanus’s description of Africa was one of the most important sources available in Europe from the second half of the 16th century as a basis for the development and expansion of the descriptive geography of Africa. Shortly after the book was printed by G. B. Ramusio in the year 1550, it was translated and adapted into several languages. In the preface to his French translation, Ch. Schefler made an excellent study on the way in which European authors, from the 16th to the 18th century, depended on Leo Africanus’s book.

The maps of Africa and South Asia which were probably introduced to Italy by Leo Africanus had a substantial influence upon the further development of cartography in Europe. Copied by Ramusio and circulating under both their names, those maps are southern-oriented according to Arab custom and, with their scales of longitude and latitude, clearly betray an Arab origin. They led to a break with the 78 cartographic depiction of the oikoumene that had

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409 v. ibid, vol. 10, pp. 383-396
410 v. F. Sezgin, op. cit. vol. 10, p. 388
412 v. F. Sezgin, op. cit. vol. 11, p. 103, note 1.
emerged after the publication of Ptolemy’s Geography in the early 16th century. The turning-point is marked by the Asia map by the Italian cartographer Giacomo Gastaldi (d. 1567), which appeared around 1560. Before that, from 1539, Gastaldi had been devoted to the publication of Ptolemaic maps.\(^\text{415}\) The development of mathematical geography and cartography on the Indian subcontinent, which is still hardly understood in detail, ought to be considered here as well. As mentioned above, in the first half of the 5th/11th century, al-Bīrūnī himself had already determined the coordinates of some important points on the Indian subcontinent in the course of an extended project. This was the most that an exceptionally assiduous scholar could possibly achieve in several years of hard work. The remaining work took the subsequent generations several centuries to finish. According to our current knowledge, the latitudes of key points on the coast and bearings between these seem to have been determined in the 7th/13th and the 8th/14th centuries to such an extent that a delineation of the peninsula’s configuration became feasible.\(^\text{416}\) It was decisive for the beginning of the mathematical survey of the inland areas of the country that the scientific activities of the Samarqand school of the Timūrid period were relocated to India, together with political power, after the foundation of the Mogul empire by Bābur in 932/1526. In the following period, lasting about two centuries, emphasis seems to have been placed on collecting data for the mapping of the inland areas. The oldest known document of this type goes back to the second half of the first century of the Mogul Empire. It is a large volume of tables produced in India itself. Its author, Abu l-Faḍl ‘Allāmī (b. 958/1551, d. 1001/1593), was a statesman from the realm of the Mogul emperors. In the third part of his Akbarnāma, a history of the Mogul Empire, which under the independent title Āʾīn-

\(^\text{nāma}\) combines anthropogeography with an excellent descriptions of social, administrative and fiscal institutions, he provides a large table of coordinates with 656 places including 45 cities in India, and registers 3050 smaller towns, partly specifying distances. The quality of the coordinates of the Indian places is consistently high. The latitudes are almost identical with present-day values and the longitudes differ just slightly.\(^\text{417}\) The data compiled in the Āʾīn-nāma which were probably selected from special contemporary sources and the abundant material from the first half of the 11th/17th century\(^\text{418}\) convince us that the mathematical survey of the Indian subcontinent had reached a high standard under Islamic rule. Credit for the oldest known document showing the remarkable standard in the depiction of India in the 10th/16th century must go to the Dutchman Jan Huygen van Linschoten. In 1596 he published a map in Amsterdam that he had brought back from India.\(^\text{419}\)

Here we leave the cartography of the Indian subcontinent and proceed to the science of navigation in the Indian Ocean. Even though it apparently had reached its climax as early as in the 9th/15th century, the specifics of this navigation based on trigonometric-astronomical methods \[79\] were expounded only in the first quarter of the 10th/16th century in the works of Sulaimān al-Mahri. This latest master navigator known to us also regarded navigation as a science consisting of theory and experience, and, particularly as regards details, subject to the law of evolution. From this discipline, which over the centuries developed into an independent branch of science, we shall mention the three pillars on which it rests:

1. Determining the latitude at sea using the pole star and the circumpolar stars whose upper and lower culminations serve for determining

\(^\text{415}\) v. F. Sezgin, op. cit. vol. 11, pp. 92-93, 97, 99 ff., vol. 12, pp. 177-181, 252, 311.
\(^\text{416}\) v. ibid, vol. 11, pp. 565-567.

the altitude of the pole which in turn yields the geographical latitude of a place.

2. Mathematical-astronomical measurements of distances on the open sea, distinguished by Sulaimān al-Mahrī with the term *hisābī* (“mathematical”) from those that are achieved empirically, “according to experience” (*taġriba*).

3. Determining of the position on the open sea. Here the distances to be measured and the methods of measurement are of three kinds:

a) The first and most simple case is the latitudinal distance, running parallel to the meridian. For its determination it is sufficient to measure the altitude of the pole while setting out and once again after sailing for some time; the measurements are taken either in degrees or the thumb-width unit *išba* (1 *išba* = 1° 36′ 26″ or 1° 42′ 51″), the difference can be converted into distances.

b) In the second case the distance may run at any angle oblique to the meridian. It is found by taking, in degrees, the altitude of the pole and measuring the angle of the course to the meridian at the time of putting to sea. After sailing for some time on that course, the altitude of the pole is again taken. With this data, a right-angled triangle is constructed. The hypotenuse, i.e. the side opposite to the right angle, is the sought distance.

c) In the third case the distance is longitudinal. This was used for measuring distances between places of the same latitude situated on opposite seacoasts, i.e. determining distances parallel to the equator. The method is equivalent to the determination of longitudinal differences between two points on the coast or at sea. The navigator first proceeds as described under b), that is to say, he sails a certain distance at a known angle oblique to the meridian. After determining this first distance he takes a course opposite to the one sailed before and maintains this course until he reaches the same altitude of the pole that was registered at the outset. With the known angles of the courses and the difference in the measured altitude of the pole, the navigator constructs two right-angled triangles with one common side, consisting of the measured difference in the altitudes of the pole. In order to arrive at the sought longitudinal difference between the two opposite coastal points, the navigator must continue cruising between the two established altitudes of the pole until he has reached the desired coastal point. By adding up the base lengths of all triangles he finally gets the total distance in *zām* to be converted in degrees of longitudes or miles.

Procedure c) was in the true sense of the word triangulation on the high seas, roughly five hundred years after Abu r-Raiḥān al-Bīrūnī used the triangulation method on land for establishing longitudinal differences of localities between Baghdad and Ghazna. In order to handle this method, the application of trigonometric rules was required, besides a certain knowledge of astronomy. This mathematical method was well developed and widespread in the Arabic-Islamic world, but of course it was not suitable for every mariner to use. Those lacking the required skills could resort to available tables while measuring distances oblique to the meridian.

[80] Prior to the introduction of the compass, orientation on the open sea and maintaining a set course at night was guided in the Indian Ocean by the North and South Star and by fifteen fixed stars which in their points of rising and setting are approximately 11° 15′ apart; this led to a division of the horizon in thirty-two parts. The time when the knowledge of the compass reached the Arabic-Islamic area cannot be precisely determined, but it was presumably in the 3rd/9th or 4th/10th century. It seems that the magnetic needle in its primitive form originated in China, but was first systematically used for navigation by the navigators of the Indian Ocean.421 Besides the numerous references in Arabic sources, the Portuguese also frequently provide perspicuous information on the various types of compasses.

420 v. F. Sezgin, op. cit. vol. 11, p. 199.
used in the Indian Ocean. The Portuguese historian Hieronimus Osorius (1506-1580) gave a particularly impressive account of the three stages in the development of the compass with Arab navigators. In the third type, the bowl carrying the disc with the magnetic needle was suspended in a cylindrical arrangement which later came to be known as “cardan” suspension. This type apparently already reached the Italian seafarers in the Mediterranean in the 15th century, and also Christopher Columbus took such a compass with him. It was the type of mariner’s compass commonly used in Europe until the 20th century, when the magnetic needle was separated from the cardboard disc and placed on a pin above the disc. If we understand Ibn Māqīd’s statement correctly (supra p. 72 and III, 67), he was the originator of this innovation which at first obviously did not enjoy much circulation.

The distances between ports, islands, capes and bays of the Indian Ocean recorded by the two great navigators, Ibn Māqīd and Sulaimān al-Mahri, are remarkably close to modern values. Of the greatest significance are particularly the seven trans-oceanic distances given by al-Mahri, between the east coast of Africa and Sumatra or Java; of these the route passing approximately 1° north of the equator deviates by only half a degree from the present-day value. Quite remarkably the same precise length of the equator appears around 1519 in a map drawn in Portugal by Jorge Reinel—which can only mean that a copy from an Arabic original served as a model here. Such accuracy was not found again until the second half of the 19th or even to the first half of the 20th century.

We can take for granted the fact that such data, collected for centuries in the context of a navigation based on mathematics and astronomy, would lead, in the hands of cartographers, to maps of high quality. While Portuguese seafarers and other European travellers repeatedly mention nautical charts by local navigators on the Indian Ocean and in particular point out that longitudes and latitudes were indicated on these maps, some of those charts survive in Portuguese copies. The fact that the two great representatives of navigation in the Indian Ocean hardly ever mention any maps was used by some historians of cartography to argue that this nautical aid was unknown or unavailable to them. The lacuna is now filled by the [81] Kitāb al-Muhīṭ (“Book of the Ocean”) by the Ottoman admiral Sīdī ‘Alī (d. 970/1562), which only was made fully accessible to research in a facsimile edition a couple of years ago. This naval officer, who was usually operating in the Mediterranean, had suffered great losses through Portuguese attacks while fulfilling a mission in 960/1553 to take fifteen ships of the Ottoman fleet from al-Baṣrā to as-Suways (Suez). The remainder of his fleet landed near Sūrat on the west coast of India. During a subsequent stay in Ahmadabād (961/1554) he wrote his book, basically summarising the contents of several works by Ibn Māqīd and Sulaimān al-Mahri. In the four sections of the seventh chapter devoted specifically to maps, his presentation leaves no doubt that a navigation based on the calculation of distances and determination of bearings could not do without appropriate charts, neither in the Mediterranean nor in the Indian Ocean. He mentions three types of maps: charts of the

429 v. ibid, vol. 11, p. 253-256.
432 cf. ibid, vol. 11, pp. 93-99.
Indian Ocean, of the Mediterranean, and world maps. On the whole, it becomes clear that he understands maps as the representation of the mathematically surveyed surface of the Earth and that for him navigation can be practised only with the help of charts, magnetic compasses, dividers, and instruments such as the astrolabe or the quadrant.439

Besides the charts of the Indian Ocean supported by the measurements taken by navigators and besides the two main nautical instruments—the compass and the surveying instrument known in Europe as Jacob’s staff440 or balhestitilha (Arabic ḥaṣābat or ḥaṭabāt)—the method of measuring distance oblique to the meridian was also introduced into Europe. It was called toleta de marteloio and reached Italy in the 15th century.441 Regarding the advanced navigation which originated in the Indian Ocean, the Portuguese deserve the credit for having helped its wide dissemination in Europe, within the bounds of their understanding. However, it has been established beyond doubt that the measuring of distances between two points of the same latitude on opposite coasts, i.e. the determination of trans-oceanic longitudinal differences—perhaps the most significant achievement of this nautical tradition—remained a closed book to them. That is, they appear to have known the problem as such,442 but it seems they lacked the necessary trigonometric expertise to understand the procedure.443

With this overview of the field of navigation I would have concluded my survey of the most important achievements of the Arabic-Islamic world known to me, and would have moved on to the discussion of their influence on the western world, yet I feel that by completely excluding the 11th/17th century I would do injustice to an eminent philosopher of this period. I am referring to Ṣadraddīn Muḥammad b. Ibrāhīm Ṣirāzī, known as Mullā Ṣadrā (b. ca. 980/1572, d. 1050/1640) whose important position in the history of philosophy was brought to light only in 1912 thanks to Max Horten. The latter called Mullā Ṣadrā “one of the great unknown figures in the history of humanities. In the narrow and meagre confines of the teaching profession he found time and energy to expound his own view of the world” [82].434 Based on Ṣīhābaddīn as-Suhrawardī’s (d. 587/1191) light-theory, he formulated his theory of “evolutionary stages of being” in which “the concept of light was replaced by being.” Through this shift Ṣirāzī came to “a point of view from which he remolds the entire philosophy of his days.”435 With great self-assurance, so Horten, he confronts the current philosophy. In his system he combines the entire heritage of Greek philosophical learning with mysticism. He considers Aristotle and Ibn Sinā as the greatest philosophers ever. They are followed by Plato and as-Suhrawardī; Fāhraddīn ar-Rāzī (d. 606/1209) is esteemed as the great critic of Aristotelian philosophy. However, according to Horten, Mullā Ṣadrā’s philosophy was not merely borrowed from the teachings of those masters, but was a deliberate attempt at a continuation of Ibn Sinā.436

With this brief reference to the importance of Mullā Ṣadrā in the field of philosophy, I conclude the examples for the contribution made by the Arabic-Islamic world area to the history of science. This closing however is not meant to imply that subsequently there were no occasional further achievements of significance. Yet with the end of the 10th/17th century we find ourselves on the threshold of the period in which, in the field of sciences, the West begins to take the

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440 v. ibid, vol. 11, pp. 302-306
441 v. ibid, vol. 11, pp. 289-294.
433 v. ibid, vol. 11, p. 287.
433 v. ibid, vol. 11, p. 319.
lead in the field of sciences and in which it will relieve the Islamic world of this role. Keeping this in mind, the present overview would fail its aim if the enormous complex of the reception and assimilation of Arabic-Islamic science in the Occident remained outside our purview. However, within the confines of this introduction, such an attempt can only consist in hints towards the most basic issues, particularly as a comprehensive presentation of the matter, apt to historical reality, cannot also be expected for a long time to come.
Principal routes of science from the Arabic-Islamic world into Europe