
The Enterprise of Science in Islam edited by Jan P. Hogendijk and A. I. Sabra

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This collection, which is based on a conference on new perspectives in Islamic science held in 1998 at MIT's Dibner Institute, provides a snapshot of current research in this rich field for specialists and non-specialists alike. Established scholars have contributed each of the 12 articles, and while they do not cover all fields (e.g., scientific instruments and theoretical astronomy are omitted), the articles are nevertheless wide-ranging. The editors, Jan P. Hogendijk and A. I. Sabra, have divided the articles into categories which are generally topical: cross-cultural transmission; transformations of Greek optics; mathematics; philosophy and practice; numbers, geometry, and architecture; 17th-century transmission of astronomy; and science and medicine in the Maghrib and al-Andalus. To provide an additional perspective, I will group the chapters into four general categories (Transmission; Critique; Awareness of Disciplines; and Theory, Practice, and Applications); and because the volume deserves a wide readership, I will attempt to explain the relevance of each chapter to the field of Islamic science and to the general history of science.

Transmission

Those who use Hindu-Arabic numerals know something of the numerals' origin through their name. Hindu-Arabic numerals, though, resemble the numerals of the Muslim West much more closely than the numerals of the Muslim East. Paul Kunitzsch [3-21] addresses the transmission of these numerals (from the Muslim East to the Muslim West, in particular) and agrees with the scholarly consensus that the Arabs received their system of nine decimal numerals and a zero from India most likely in the eighth century (all dates are AD).

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The numerals were used for reckoning on a board (*takht*) covered with dust (*ghubār*). In the Islamic West, this same type of reckoning was called *ḥisāb al-ghubār* (Hindu reckoning, literally dust-board reckoning).

The development of the Western forms of Hindu-Arabic numerals was gradual. Certain Latin mss from Spain from as late as the 15th century retained the Eastern forms of the numerals, whereas Latin mss from the 10th century began to have the Western forms. Some have suggested that the numerals came to the Islamic West *via* Spain, or that certain numerals (5, 6, and 8) derive from European models. In light of similarities between the Eastern and Western forms of the numerals, though, Kunitzsch suggests that the Western forms developed directly from the Eastern forms, and that the most likely route of transmission for the numerals was through texts on Hindu reckoning. Because no Arabic mss with the Western forms of the numerals from before the 13th century have been discovered, more detailed conclusions about the precise origin of Hindu-Arabic numerals are premature.

Another well-known instance of transmission was the passage of certain scientific texts from the Islamic world to Europe to spur what Haskins [1957, 278–302 or 1927, 109] famously called the 12th-century renaissance. Charles Burnett's chapter 'The Transmission of Arabic Astronomy via Antioch and Pisa', though, broadens our understanding of transmission in the Middle Ages both chronologically and geographically. A close comparison of the Greek and Arabic versions of the *Almagest* shows that MS Dresden, Landesbibliothek, Db. 87 is a translation of the first four books of the *Almagest* made directly from Arabic into Latin in the first quarter of the 12th century, before the better-known period of transmission noted by Haskins. Similarities between numerical notations in the Dresden *Almagest* and the *Liber Mamonis*, and the use of eastern numerals in the latter, lead Burnett to date the *Liber Mamonis* to the same period. His conclusion is that Stephen of Pisa and Antioch composed the *Liber Mamonis* and that ʿAbd al-Masīḥ of Winchester, from the same circle of translators, translated the Dresden *Almagest*. The Dresden *Almagest*, then, represents the earliest Latin translation of the *Almagest* and the *Liber Mamonis* is evidence for an equally early reception of Ptolemaic cosmology. The *Liber Mamonis*, however, does not depend directly on the Dresden *Almagest*. The connection between

the *Liber Mamonis* and Antioch is made by virtue of its relation to a third work, the *Tables of Pisa*. Perhaps these early instances of transmission from the Eastern Mediterranean spurred translations later in the 12th century in Spain and Sicily.¹

David Pingree's chapter, 'The Sarvasiddhāntarāja of Nityānanda', extends the chronological scope of the study of the transmission of science within the Islamic world into the 17th century.² Shāh Jahān (the builder of the Taj Mahal) had a vizier, Āsaf Khān, who charged the scholar Nityānanda with the translation into Sanskrit of *Zīj-i-Shāh-Jahānī*, a recent ephemeris (*zīj*) based on Ulugh Beg's (d. 1449) *Zīj-i-Jadīd* (*The New Ephemeris*). The translation, entitled *Siddhāntasindhu*, was completed in the early 1630s. As Pingree [1996, 474] has found, those features of Islamic astronomy most closely connected with Aristotelian philosophy, particularly a solid-sphere universe, were extremely difficult for Indian astronomers to accept. Indeed, in 1639, Nityānanda composed the *Sarvasiddhāntarāja*, an apology for using Islamic astronomy in the *Siddhāntasindhu*. In the following passage the *Sarvasiddhāntarāja* posits Indic origins for Islamic astronomy:

the Sun, because of the curse of Brahmā, became a Yavana [i.e., Muslim] in the city of Romaka and was known as Romaka. After the curse was lifted, he became the Sun again, and wrote the *Romakasiddhānta* 'which has the form of revelation (*śrutirūpam*)'. [Pingree 1996, 478]

Nityānanda claimed to be repeating the *Romakasiddhānta* and he effectively argued throughout the *Sarvasiddhāntarāja* that Indian and Islamic astronomy were not really that different.

In the *Sarvasiddhāntarāja*, to facilitate computations, Nityānanda converted the mean motions from Arab years and months, and so forth, into integer numbers of revolutions per Kalpa of 4,320,000,000 years. The text contains algorithms for computing each planet's equation, and the near equivalence of the equations in both astronomies

¹ Compare the flourishing of translations in Abbasid society in which existing knowledge created a demand for more translations: see Gutas 1998, 137 and Saliba 1998, 69–72.

² Pingree has been working on the transmission of Islamic science to India for some 25 years: see, e.g., Pingree 1978, 315–330.

was another part of Nityānanda’s argument for their similarity. Given that Indian astronomers did not favor the system of physical movers found in Islamic astronomy, Pingree, with help from Kim Plofker, reconstructs Nityānanda’s geometrical rationales for computing the equations. Pingree’s work is valuable because the date at which the transmission took place both indicates the continued vitality and usefulness of Islamic astronomy and encourages more research on Islamic astronomy in India.³

Finally, Julio Samsó’s chapter, ‘On the Lunar Tables in Sanjaq Dār’s *Zīj al-Sharīf*’, addresses 17th-century transmission between the Muslim East and West. Earlier astronomers from the Muslim West, such as Ibn al-Zarqālluh (d. 1100), invented models that explained variations in the rate of the precession of the equinoxes (trepidation), and in turn entailed variations in the obliquity of the ecliptic. There is evidence for observations in the Muslim West from the 13th and 14th centuries which put into question the viability of these models for precession. Such attacks apparently motivated astronomers in the Muslim West to replace their *zīj*es with *zīj*es from the Muslim East based on a constant rate of precession. Samsó argues, through computer analysis of the tables for lunar motion in the *Zīj al-Sharīf*, that Ulugh Beg’s *Zīj-i Sulṭānī* reached Tunisia in the 17th century. And so, as Pingree did, Samsó demonstrates that the often overlooked 17th century was not a period of stagnation. Additionally, Samsó calls attention to how astronomers from the Muslim West critiqued and replaced their own theories.

Critique

Research over the past century⁴ has demonstrated that the scientists of the Islamic world, over several centuries, both critiqued the Hellenistic heritage and developed new theories to replace ones deemed

³ See Pingree 1976, 109: ‘The Sanskrit texts, however, though often either incorrectly or not at all understood by those who have transmitted them to us, formed the basis of a scientific tradition that only in this century has been destroyed under the impact of Western astronomy.’ See also Pingree and Kusuba 2002.

⁴ See, e.g., de Vaux 1896; Dreyer 1906, 262–280.

flawed.⁵ Until recently, these important general conclusions were typically defended on the basis of Islamic achievements in astronomy. But just as the preceding section on transmission encouraged investigations of less well-known instances of transmission, the volume under review also reflects scholars' growing awareness of a critical and perhaps revolutionary attitude in areas of Islamic science besides astronomy. In 'Ibn al-Haytham's Revolutionary Project in Optics: The Achievement and the Obstacle', A. I. Sabra argues that the achievements of 13th- and 14th-century astronomers of Islam may in fact not be as revolutionary as others have alleged,⁶ but the work of Ibn al-Haytham (= Alhazen, d. 1040)⁷ on optics was. Ibn al-Haytham was not only the first writer on optics in the Islamic world to evince awareness of Ptolemy's *Optics*, which had superseded Euclid's *Optics*, he was also the first to overthrow Ptolemy's theory of vision. Sabra, an authority on Ibn al-Haytham, argues that Ibn al-Haytham's rejection of the two main earlier theories of vision (the intromission of forms from the object to the eye and the extramission of a visual flux from the eye to the object) and creation of his own theory of vision should be considered revolutionary.

By any measure, Ibn al-Haytham's phenomenological explanation, in mathematical language, of how light enables the formation of an image in the eye represented a radical transformation of the discipline. His *Kitāb al-Manāẓir* included the psychology of vision and his sophisticated understanding of refraction helped explain why the eye's crystalline humor sensed some forms of light and color which reached the eye but not others.⁸ Ibn al-Haytham would have a substantial influence on European optics. Although Sabra's conclusions about Islamic astronomy are not fully accepted,⁹ his engaging chapter should draw the attention of all to Islamic optics, a field which has sometimes been overshadowed by Islamic astronomy.

⁵ For a critique of Ptolemaic astronomy in the ninth century, see Saliba 1994a, 115–141. For a 16th century critique, see Saliba 1994b, 15–38.

⁶ Sabra 1998b criticizes the claims of some historians of Islamic astronomy.

⁷ Sabra 1998a addresses the question of Ibn al-Haytham's identity.

⁸ See Sabra 1972, 1978, 1987, and 1989.

⁹ See Saliba 2000 and Sabra 2000.

Tzvi Langermann's article, 'Another Andalusian Revolt? Ibn Rushd's Critique of al-Kindī's Pharmacological Computus', investigates whether there was an Andalusian critique of medical texts resembling the Andalusian critique of Ptolemaic astronomy which Sabra [1984] has described. Langermann focuses on the critique offered by Ibn Rushd (= Averroes, d. 1198) in his *al-Kulliyāt fī al-ṭibb* (*The Generalities in Medicine*) of the computus proposed by al-Kindī's computus in his *Fī ma'rifat al-adwiya al-murakkaba* (*On the Knowledge of Compound Medicines*). There al-Kindī ranked the qualities of non-temperate drugs in four degrees. A drug in the first degree was twice as powerful as a temperate drug and one in the second degree was *four* times as powerful, and so forth. Ibn Rushd responded by presenting his own rules or laws (*qānūn*, pl. *qawānīn*) governing the use of compound drugs. The most complex rule was that when dealing with drugs composed of simples of opposite qualities, the result could be determined by simple computations of the drugs' powers not of their weights. So, two units of a cold drug of the first degree should reduce a hot drug of the third degree by two degrees. (Al-Kindī's principle had predicted a reduction of a single degree.) Then, Ibn Rushd went on to criticize al-Kindī's computus for, among other things, classifying some drugs to be so strong relative to the first degree that they would be fatal.

Ibn Rushd's attacks were an exception to the general lack of interest in al-Kindī's computus. Most pharmacologists were more interested in the medical formulae themselves, and not as interested as Ibn Rushd was in methodological frameworks grounded ultimately in Aristotle. Langermann situates Ibn Rushd's critiques of al-Kindī within the context of an Andalusian effort to construct alternatives to the science coming from the Muslim East. There are clear parallels between the methodological critique of al-Kindī and the view that Ptolemaic astronomy, hence aspects of the astronomy of the Muslim East, contradicted Aristotle's physics. Recently Saliba [1999a] has argued that while there was certainly a distinctively Andalusian philosophy, there was not necessarily a substantial Andalusian astronomy.¹⁰ Langermann's chapter suggests, then, that a solution to the

¹⁰ In a paper currently in preparation, I argue that Ibn Naḥmīas' improvements on al-Bitrūjī (*ca* 1217), a subject of Sabra 1984, indicate a rapprochement with astronomy from the Muslim East.

debate will depend on other fields besides philosophy and astronomy. Thus, both Langermann and Sabra's chapters encourage researchers to look beyond astronomy for examples of Islamic science's critical attitude.¹¹

Awareness of Disciplines

To understand the historical relationship of various scientific disciplines better, historians of Islamic science have relied on pre-modern catalogues of the sciences. In 'The Many Aspects of "Appearances": Arabic Optics to 950 AD', Elaheh Kheirandish carefully reads the three pages on optics (*'ilm al-manāẓir*) in al-Fārābī's (d. 950) *Iḥṣā' al-^culūm* (*Enumeration of the Sciences*) as a starting point for determining the state of the discipline in the 10th century. Kheirandish demonstrates how problems of transmission, particularly the accurate or inaccurate translation of technical terms, influenced the direction of research. She examines five passages from *Iḥṣā' al-^culūm* which first address the matter of why objects visible at a distance appear to be different from the way they really are. It is this epistemological question that distinguishes optics from geometry: al-Fārābī does not mention the related matter of the veracity of vision (*ṣidq al-ru'ya*). The second passage focuses on the reasons *why* certain appearances are at odds with the real properties. Kheirandish speculates [61] that these questions arose due to the impaired transmission of Euclid's theory of vision, in which visual rays proceed from the eye to the object of vision, and in which 'that on which more of the ray falls is seen more accurately' [see Kheirandish 1999].

From a third passage we learn that while al-Fārābī was quite interested in applications of optics, he said little about surveying and catoptrics (mirrors). Kheirandish supplies the missing background. The use of *mun^cakis* (reversed) to mean 'reflected' instead of *mun^catīf* (reflected) led to misunderstandings about how heights could be determined by reflecting visual rays. Problems of transmission also

¹¹ Langermann mentions other texts with critiques of Galen: see Abū Bakr al-Rāzī, *al-Shukūk 'alā Jālīnūs* [Mohaghegh 1993] and Pines 1986. We know, too, of Ibn al-Haytham's solutions of criticisms of Euclid: see Ibn al-Haytham *On the Resolution of Doubts in Euclid's Elements and Interpretation of Its Special Meanings* [Sezgin 1985].

explain why, in the fourth passage, al-Fārābī's Euclidean theory of vision lacks particular terms for perception (*idrāk*). In the the final passage al-Fārābī's limited knowledge of refraction confirms Sabra's important comment that early writers on Islamic optics did not understand Ptolemy's account of refraction. Kheirandish's chapter, then, connects the chapters on transmission with Sabra's chapter on Ibn al-Haytham. She has shown that catalogues of the sciences may prove to be as informative for scholars of Islamic optics as they have been for scholars of Islamic astronomy [cf. Saliba 1982].

In addition to catalogues of the sciences, the work of one scientist can also yield a sense of the direction of a discipline, as J. Lennart Berggren has found with the works of the 10th-century mathematician Abū Sahl al-Kūhī (or al-Qūhī). In 'Tenth-Century Mathematics through the Eyes of Abū Sahl al-Kūhī', Berggren draws on his extensive research on al-Kūhī and that of Hogendijk, to argue that al-Kūhī's choice of problems was determined by Hellenistic geometers and that al-Kūhī was the last mathematician to adopt their perspective.

Indeed, the intersection of al-Kūhī's work with other fields of Islamic science to which he also contributed stems from his broad definition of geometry. Al-Kūhī wrote a substantial and much discussed treatise on the stereographic projections (the representation of a three-dimensional object in two dimensions) necessary for astrolabe construction.¹² He also applied geometrical methods to determine if an infinite motion could occur in a finite time period [see Rashed 1999]. In an article that appeared after Berggren wrote his chapter, Rashed [2001] finds that al-Kūhī's geometrical analyses of observational techniques helped meteorology become a part of astronomy. After al-Kūhī's death, scientists continued to re-evaluate disciplinary boundaries. Ragep's work on Naṣīr al-Dīn al-Ṭūsī (d. 1274), and on the relationship between astronomy and philosophy, provide later examples of how mathematics approached questions which had traditionally been in the domain of philosophy (*falsafa*) [see Ragep 1993, 2001]. Such reconsiderations of disciplinary boundaries are a

¹² See Berggren 1991, 1994. Abgrall 2000 draws on earlier work of Roshdi Rashed in continuing to investigate al-Kūhī's work on the astrolabe. See also Rashed 1993, 2000.

reminder that despite religious scholars' critiques of *falsafa*, the investigation of some of the problems which philosophy addressed could continue.

Ahmed Djebbar's article, 'A Panorama of Research on the History of Mathematics in al-Andalus and the Maghrib Between the Ninth and Sixteenth Centuries', examines the development of the history of the mathematics of the Muslim West. Ibn Khaldun (d. 1407), in his *Muqaddima*, catalogued the sciences and effectively shaped the research agenda until 1980 for the history of mathematics in the Muslim West. An emphasis on arithmetic and algebra is notable. Since 1980, research (and Djebbar has been associated with a great deal of it) has focused on the beginning of mathematics in the Muslim West, the communication of ideas and circulation of scientists between the Muslim East and the Muslim West, and the reasons for the strikingly low level of content in mathematical handbooks. Djebbar concludes his survey by identifying areas for future research such as the details of the transmission of Euclid's *Elements* and why calculation dominates post-Almohad (after 1269) mathematics in the Muslim West. Djebbar posits societal reasons for the latter. Djebbar's chapter, like Langermann's, investigates reasons for regional variations in the enterprise of Islamic science.

Theory, Practice, and Applications

Ibn Rushd's concern for methodology, which we noted in the chapter by Tzvi Langermann, is a theme of Gerhard Endress' 'Mathematics and Philosophy in Medieval Islam'. Drawing inspiration from Ibn Rushd's statement in his *Commentary on Aristotle's Metaphysics Book Λ*,

In our time, astronomy is no longer something real; the model existing in our time is a model conforming to calculation, not to reality. [Genequand 1984, 179]

Endress traces the parallel history of two approaches to truth in Islamic philosophy and science. One was a theoretical reality derived from a close reading of Aristotle and the other, the mathematicians'

(i.e., Ptolemy's) reality based on mathematical and geometrical theories which explained, in practice, the available observations.¹³ Ibn Rushd hoped that the recovery of the true Aristotle would reconcile the two approaches, yielding a philosophical account of the heavens' matter and form that would also explain their observed motions.¹⁴

Al-Kindī formulated the first notable compromise between the two approaches in his treatise entitled *Philosophy Can Be Acquired through the Science of Mathematics Only* [see Tajaddud 1971, 316]. Another significant step came with Ibn Sīnā (d. 1037), who presented all of the sciences according to the syllogism of Aristotle's *Posterior Analytics*. Ibn al-Haytham used a generally Aristotelian method of demonstration to conclude in the *Shukūk 'alā Baṭlamyūs* (*Aporias against Ptolemy*) that some of the principles Ptolemy used to account for observations could not both account for the observations and be in accord with theories of physics, and that these principles would have to be changed [see Sabra and Shehaby 1971, Sabra 1998b]. Following an examination of the attempts by Andalusian philosophers to restore Aristotle's cosmos, Endress discusses how the theologians' critique of philosophy forced scientists to re-examine their attachment to philosophical principles. Some scientists, while acknowledging the impossibility of making a claim for science's absolute truth, argued for the value of the scientific process [see Ragep 2001, Sabra 1994]. Others questioned the need for such a strong critique of philosophy [see Morrison 2002 and 2004]. Endress' chapter, then, dovetails nicely with recent research (and Berggren's chapter) showing that Islamic astronomers after Ibn Rushd became well aware of the extent to which their science did and *did not* have to rely on Aristotelian philosophy.

While the possibility of a connection between developments in Islamic mathematics and their practical applications to architecture has always seemed strong, the demonstration of such a relationship and its details are remarkably slippery [see Saliba 1999b, 641]. Yvonne Dold-Samplonius' chapter, 'Calculating Surface Areas and

¹³ Not only did Ptolemy's theories suffer from the well-known difficulty of the equant, but later Islamic astronomers would doubt his method of computing planetary distances. See Hartner 1964, 1.282.

¹⁴ Both Harvey 1999 and Mesbahi 1999 investigate the extent to which Averroes was a return to Aristotle.

Volumes in Islamic Architecture’, argues strongly for a certain connection between pure mathematics and its applications and thereby illustrates which other connections have yet to be fully understood. In earlier articles, Dold-Samplonius has analyzed calculations of domes and *muqarnas* (an architectonic and ornamental form characteristic of Islamic architecture); now she focuses on arches and vaults.¹⁵ Her study of the last chapter of Ghiyāth al-Dīn al-Kāshī’s (d. 1429) *Miftāḥ al-ḥisāb* (*Key of Arithmetic*), entitled ‘Measuring Structures and Buildings’, shows that ‘al-Kāshī uses geometry as a tool for his calculations, *not* for constructions [239].

Since al-Kāshī’s goal was to measure these architectural forms, not to construct them, he used methods of approximation. While a mathematical analysis of any type of arch would clearly have been within al-Kāshī’s ken, his text facilitated approximations by showing readers how to fit their calculations to one of five models of arches. Dold-Samplonius has evidence that architects in 17th-century Safavid Iran were paid according to the height and thickness of walls, and she tentatively extends this finding to al-Kāshī’s milieu. Finally, she interprets the evidence for architectural applications of mathematics carefully and suggests that some of the applications, particularly the calculation of a *muqarnas*, were rarely carried out due to their complexity.

Although magic squares served primarily as brain-teasers, Jacques Sesiano’s chapter, ‘Quadratus Mirabilis’, uses them to elucidate a previously unknown level of complexity in 10th-century number theory. A magic square (there is no single appellation in Arabic) is a square array of integers with the sum of each row, column, and diagonal being equal [xv]. The order of the square is the number of cells on a side, and a bordered magic square (for orders of five and up) retains the properties of magic squares as rows are removed from the perimeter. The placement of numbers in a bordered square was always determined by a rule. If k is a natural number, an odd square has order $2k + 1$, and evenly-even square has order $4k$, and an oddly-even square has order $4k + 2$. The earliest texts on magic squares are *Treatise on the Magic Disposition of Numbers in Squares*

¹⁵ On the measurement of the dome (*qubba*), see Dold-Samplonius 1992 and 1993. On the measurement of the *muqarnas*, see Dold-Samplonius 1992–1993 and 1996.

by Abū al-Wafā' al-Būzjānī (d. 997 or 998) and a chapter from 'Alī ibn Aḥmad's (d. 987) *Commentary on Nicomachus' Arithmetic*.

Sesiano's chapter examines solutions to the difficult problem of constructing an odd bordered square with the even and odd numbers separated by a central rhombus whose corners are in the middle of the square's sides. Both authors begin by filling the inner square of the rhombus by basically constructing a bordered square with only odd numbers. After that, the authors diverge. Al-Būzjānī's solution is the earliest of the two that survive, but the placement of some of the numbers was ambiguous. Al-Anṭākī's solution, which Sesiano believes not to be due entirely to al-Anṭākī, explains how to place the remaining odd and even numbers in the rhombus and how to complete the rest of the square. Sesiano provides a detailed analysis and a translation of the relevant parts of the text. Later, in the 13th century, magic squares would become increasingly tied to occult practices and research into their theoretical foundations dissipated. Sesiano has found a remarkable level of theoretical sophistication within what might at first appear to be a more marginal use of Islamic mathematics than architecture.

The editors deserve much credit for assembling an eminent group of scholars whose solid articles represent important trends in the history of science in Islam.

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