JHA, xxxvii (2006)

ESSAY REVIEW

ISLAMIC SCIENCE AT ITS BEST

In Synchrony with the Heavens: Studies in Astronomical Timekeeping and Instrumentation in Medieval Islamic Civilization, i: *The Call of the Muezzin*. David A. King (Brill, Leiden, 2004). Pp. lviii + 930. $302. ISBN 90-04-12233-8.

In Synchrony with the Heavens: Studies in Astronomical Timekeeping and Instrumentation in Medieval Islamic Civilization, ii: *Instruments of Mass Calculation*. David A. King (Brill, Leiden, 2005). Pp. lxxvi + 1066. $358. ISBN 90-04-14188-X.

Of the sciences that were nurtured during the heyday of the Islamic civilization, most had their roots in earlier cultures, especially the classical Greek and Sanskrit. Only two of these scientific disciplines were created *a nouveau* for reasons that had to do with Islamic religion itself. The first, which came to be known as *ʿilm al-Mīqāt* (Science of Timekeeping) after the fourth century of the Islamic calendar, was brought into being as a result of the deceptively simple religious requirement of the five daily prayers that every Muslim was obligated to perform while facing in the direction of Mecca. The second, which came to be known as *ʿilm al-Farāʾiḍ* (Science of Inheritance Laws), was necessitated by the rather complicated inheritance laws that were stipulated in the Qurʾān. Taken together, the two disciplines can properly be referred to as Islamic sciences *par excellence*, since they were both inspired by religious obligations, had no equivalents in the earlier cultures, and were developed specifically to respond to religious needs. It is to the first of these that the studies in the two magisterial volumes under review are dedicated.

In order to perform the five daily prayers, Muslims have to face in the direction of Mecca, or what is commonly called the *qibla*. In the early days of Islam, when the Muslim community still lived within sight of the holy sanctuary, it was relatively easy to determine the direction of prayer. But when the community grew and spread beyond the borders of Arabia, the determination of the *qibla* was not a simple matter.

At first, it seems that the early pious men who accompanied the troops as advisors simply prayed in a direction arrived at either by sheer guesswork, or by reference to whatever celestial phenomenon they could conjure up, such as the winter rising of the Sun or its winter setting, or the rising of Canopus whenever they could see it. This may well explain the preponderance of mal-oriented mosques all over the Muslim world.

Those who knew that the Earth was a spherical body realized early on that the problem of determining a unique direction between two points on the surface of the globe required the solution of a sophisticated problem in spherical astronomy. The solution involved the manipulation of all sorts of trigonometric functions that were either poorly developed or non-existent in earlier civilizations. As a result one could say that most of trigonometry as we now know it was developed in Islamic times, and primarily as a response to such basic religious needs.

The realization that the direction of prayer depended on the longitude and latitude of specific cities with respect to the longitude and latitude of Mecca, and its solution for particular cities of the then-known Muslim world, led to the much more general question of determining such directions for any city anywhere. Since few possessed the technical means to perform such sophisticated mathematical computations, there arose the need to determine such directions graphically, by an instrument of some sort. This trend led to radical departures from the manner in which astronomical instruments such as astrolabes and quadrants were designed and manufactured, instruments whose basic stereographic projection theory was already known since classical Greek times. In particular, these departures began to appear early on, and generally entailed that during Islamic times, one would normally find on the backs of astrolabes a set of designs that could lead to the direct reading of the basic trigonometric functions of sine, cosine, tangent and cotangent, as well as a set of curves that would allow the direct reading of the *qibla* direction of five to six specified cities. In addition, one could find another family of curves that allowed for the direct reading of the solar altitude at noon for another six to seven specific latitudes. These latter curves were useful for the determination of the times of prayers, and in particular the noon (*ẓuhr*) and afternoon (*'aṣr*) prayers.

Once such individual solutions of localized problems were accomplished, the next logical step was to represent graphically the *qibla* directions of all known cities of the Muslim world. That in turn led to the creation of new methods of map projections, on instruments that were apparently started by Ḥabash al-Ḥāsib in ninth-century Baghdad, and perfected to a jewel-like status sometime during the seventeenth century of Safavid Iran, and to which David King has devoted a completely separate volume, *World-maps for finding the direction and distance to Mecca* (Brill, 1999). From these instruments one could not only tell the *qibla* of a specific city, but also determine the distance between that city and Mecca itself, by reading the angles and distances directly off the map.

The times of the five daily prayers would have been slightly easier to determine had they not been mostly defined, from the very beginning, in terms of atmospheric phenomena such as twilight and the like, or earthly phenomena like shadow lengths. All these phenomena were themselves determined by the motion of the most commanding celestial object of all, the Sun. And as Islam wished to distinguish itself from earlier star- or sun-worshipping religions it enjoined that no prayer should ever be performed when the Sun was located at an exact point like sunrise, sunset, or high noon. Instead, prayers were to be performed at dawn, for example, before sunrise, and after the time when one could tell black and white threads apart. Similarly, the evening prayer was to be performed after sunset, but before nightfall. The noon prayer was to be performed after the Sun had just crossed the meridian and gnomons had begun to cast shadows. In performing the night prayer, one had much leeway, as it could be said anytime before midnight.

The only prayer that caused a major problem was the afternoon (*'aṣr*) prayer. At first, it was to be performed between the time when the shadow of a gnomon was equal to itself and when it became twice that long. This definition was quickly abandoned as it was soon realized that for some six months of every year, in the climes just north of Mecca, whose latitude was around 21;40°, no one would ever see the shadow of a gnomon equal to its length. As a result the definition was modified to stipulate that the afternoon prayer should be performed between the time when the shadow was equal to the length it had at high noon plus the length of the gnomon itself, and the time when the shadow equalled the shadow at noon plus twice the length of the gnomon.

With the Sun changing position with respect to an earthly observer from day to day, depending on the season, and the length of day also changing for the same reason, one could easily see why such requirements would quickly lead to more serious problems of mathematical geography.

In their general scope, all such problems fell between the disciplines of mathematics, astronomy, trigonometry, map projections, and mathematical geography. Taken together, they constituted the domain that preoccupied the timekeeper of the Muslim community, whose job it was to determine the *qibla* of the locality and then of course draw up appropriate daily tables for the determination of the times for the five enjoined prayers. Eventually this development led to the institution of the post of *muwaqqit* (time keeper), within the communal mosque. And in due course the specification of this job extended into other domains, such as instrument design and craftsmanship specifically devoted to the solution of such problems. What an experienced *muwaqqit* did with his spare time, and how well he succeeded in relating his *mīqāt* (time keeping) activities to other activities, was left completely to the imagination of the particular individual. As a result, it should not strike us as strange to find a *muwaqqit* such as Ibn al-Shāṭir of Damascus (d. 1375) devoting much effort to the development of new planetary theories, or designing and executing fantastic sundials, astrolabes and other instruments. It is also easy to see the varied possibilities such developments could take and the very sophisticated problems such works could lead to.

In the end, *Mīqāt* became a fully-fledged pursuit on its own, naturally requiring much input from the very basic disciplines of mathematics, trigonometry, astronomy and mathematical geography just mentioned. And it was this that attracted the attention of David King some thirty to forty years ago, and to which he has since devoted much of his talent. As their subtitles indicate, the first of these huge and impressive volumes is devoted to texts dealing with *Mīqāt* problems relating to the times of prayers and the direction of prayers, but not exclusively so, while the second is completely devoted to instruments that allowed the solution of those problems by simply reading values from the edge of an astrolabe, a quadrant, or from a line on a sundial. Each volume has extensive bibliographies, which in themselves constitute a treasure trove, along with a series of appendices, indexes, checklists of astrolabes from all over the world, and very useful indices of technical terms and (in vol. i) sexagesimal parameters. Two of the indices list the manuscripts used for this study, with a short descriptive title of each; taken together, they constitute a survey of *Mīqāt* literature in world libraries.

Preface 2 of vol. i is a veritable essay on the place of Islamic science in the wider context of the general history of science. King argues forcefully and convincingly against such commonly held myths as Islamic science's being simply a reservoir of the classical sciences of Antiquity, especially the Greek, or that it was useful only in as much as Europe could employ it to recover that Greek science, or that it had very little to add to the Greek legacy. The only arguable point in that essay is his attribution of the age of decline (which he agrees came after the sixteenth century) to there being nothing more to discover, because, as he says, "within the medieval context, all the problems had been solved, some many times over". But King knows that his explanation does not cover the whole picture, and he wisely sends the reader to a more detailed treatment of the subject by Ahmad Y. al-Hassan (in *Islam and the challenge of modernity*, ed. by Sharifah Shifa al-Attas (Kuala Lumpur, 1996), 351–89).

In the first volume King assembles all the developments in Islamic astronomy that had to do with the Muslim religious requirements of praying five times a day, in the direction of the *Ka'ba*, together with all the attendant disciplines of mathematical astronomy, mathematical geography, trigonometry, and mathematical projections that were entailed by those requirements. King provides careful documentation of the flourish of the scientific activities that were produced by the Islamic religious requirements. He illustrates how Muslim astronomers of the past came to the rescue of their co-religionists by their production of well-tabulated solutions to the problems associated with the times of prayers and/or directions of those prayers, where the believer would simply read the result instead of attempting to perform the calculations himself. They also produced instruments that, in general, worked very much like the slide rules that used to be ubiquitous until recently.

The second of King's volumes is devoted to the construction of these instruments and to the ingenious variations that these skilful instrument-makers could produce. By reviewing these instruments one comes to realize that their very production in itself crossed the boundaries of disciplines. Each is a representation of highly developed knowledge of mathematical spherical trigonometric solutions, mathematical geography, mathematical projections, astronomy, and above all a highly developed sense of artistic production. Judging by the jewel-like results of their work, one cannot help but feel that in some instances the instrument-makers were at the same time formidable artists who should be considered as having embodied the very essence of Islamic art, namely, the art of producing an object that was first and foremost aesthetically pleasing and yet adhered to the highest sense of precision.

King expends great effort to document the remarkable phenomenon of universal applicability that seems to have permeated the whole of Islamic science, but nowhere more obviously than in the context of the *Mīqāt* literature. He seems to be the first person not to remain content with a description of mathematical instruments and how they operated, for he has searched out medieval texts that were written by instrument-makers themselves, in which they describe the construction and function of the instruments that they were producing. In particular, he is the first to explore the vast works of that first-rate timekeeper al-Khalīlī, where he discovered the solution of the *qibla* problem generalized to all known localities of his time. King was one of the first apprentices of Owen Gingerich, who attempted to use modern computers in order to verify the precision of medieval astronomical texts, and built on that to double-check the remarkable precision of the more than 40,000 entries that were produced by Khalīlī, each requiring the solution of a very complex formula involving division and multiplication of several trigonometric quantities using sines, cosines, tangents and co-tangents, all without Khalīlī's use of any calculating device that we know of. The fact that such extensive calculations seem not to have intimidated late medieval astronomers of Islam is also attested in several astronomical tables where they attempted to determine solutions for every degree of the orbit. What King documents here in Khalīlī's work seems to have been a more general phenomenon of universalizing in Islamic science that needs to be investigated further.

An astronomer/astrologer had to carry an astrolabe with a plate for the latitude of each city in which he/she (and there were female astronomers and astrologers) intended to practise his/her craft. The difficulties arising from the carrying of such bulky instruments posed challenges that must have intrigued both astronomers and instrument-makers alike. It was people like Ḥabash al-Ḥāsib of ninth-century Sāmarrā' (ii, 94) and al-Zarqālluh (d. 1100) of Spain who set the stage for the production of instruments that would function with precision at various climes (ii, 57). This activity ran its full course to climax with Ibn al-Sarrāj whose "quintuply-universal" astrolabe was made in 1328/29, and was described by King as "without doubt the most sophisticated astronomical instrument surviving from the Middle Ages and probably the most sophisticated ever made between Antiquity and 1600" (ii, 694).

So al-Khalīlī computed close to 40,000 *qibla* entries, for all of his known world. And his contemporary Ibn al-Sarrāj managed to construct a remarkable instrument whose "half of the rete that resembles one-half of a standard rete" could be used "firstly with the universal *shakkāziyya* plate, secondly with the plate of the horizons, and thirdly with a series of quarter-plates serving all latitudes[,and] then one can use the *shakkāziyya* part of the rete with the universal *shakkāziyya* plate, and finally one can use the trigonometric grid on the back to solve any of the standard problems of spherical astronomy for any latitude" (*ibid.*). Thanks to the careful documentation by King, one can now confidently assert that this universalizing tendency was part and parcel of this Islamic science, and could well be used to characterize the whole of Islamic science. This gives the lie to the periodization paradigm that had characterized these later centuries of Islamic intellectual history as a period of decline where no such sophisticated science was to be expected. And as these works were conceived and executed within the context of religious injunctions, and within the job description of the timekeeper who functioned comfortably within the bosom of the central administration of the mosque, the paradigm of conflict between religion and science that seems to work well for the history of European science begs for re-interpretation and much more nuance when it comes to Islamic civilization.

It is in the nature of such a comprehensive work to point to areas for future research. As King says, "al-Khujandī's astrolabe represents the culmination of known Muslim achievements in astrolabe construction in the early period, as the astrolabe of al-Sarrāj (Aleppo 1328/29) and the sundial of Ibn al-Shāṭir (Damascus 1371) represent the culmination of instrumentation in the later period" (ii, 505). And yet we still do not have a single full-scale study devoted to any of these scholars. The role of Khujandī in the early period, and his interest in the concept of precision that could be achieved through the development of large instruments, is of critical importance for the history of astronomy, especially when we remember that people like him, and particularly those who preceded him in the ninth century, had managed to check and improve almost every fundamental parameter in the Greek astronomical tradition — the inclination of the ecliptic, the rate of precession, the position of the solar apogee, the eccentricity of the solar model or its maximum equation, and so on.

The experience of studying these volumes will leave one amazed at the amount of theoretical mathematical and astronomical knowledge that was produced in the service of religion, and the sheer beauty of the instruments that rendered all that knowledge practicable.

Columbia University GEORGE SALIBA