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Khalīlī: Shams al-Dīn Abū ʿAbdallāh Muḥammad ibn Muḥammad al-Khalīlī

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Flourished **Damascus, (Syria)**, ***circa*** **1365**

Khalīlī was an astronomer associated with the Umayyad Mosque in the center of Damascus. A colleague of the astronomer **Ibn al-Shāṭir**, he was also a *muwaqqit* – *i. e.*, an astronomer concerned with *ʿilm al-mīqāt*, the science of timekeeping by the Sun and stars and regulating the astronomically defined times of Muslim prayer. Khalīlī's major work, which represents the culmination of the medieval Islamic achievement in the mathematical solution of the problems of spherical astronomy, was a set of tables for astronomical timekeeping. Some of these tables were used in Damascus until the 19th century, and they were also used in Cairo and Istanbul for several centuries. The main sets of tables survive in numerous manuscripts, but they were not investigated until the 1970s.

Khalīlī's tables can be categorized as follows:

(1) tables for reckoning time by the Sun, for the latitude of Damascus;

(2) tables for regulating the times of Muslim prayer, for the latitude of Damascus;

(3) tables of auxiliary mathematical functions for timekeeping by the Sun for all latitudes;

(4) tables of auxiliary functions for finding the solar azimuth from the solar altitude for any latitude;

(5) tables of auxiliary functions for solving the problems of spherical astronomy for all latitudes;

(6) a table displaying the *qibla, i. e.*, the direction of Mecca, as a function of terrestrial latitude and longitude for each degree of both arguments; and

(7) tables for converting lunar ecliptic coordinates to equatorial coordinates.

(Paris, Bibliothèque Nationale MS ar. 2558, copied in 1408, contains all of the tables in Khalīlī's major set [1, 2, 5 and 6]. Dublin, Chester Beatty MS 4091 and Bursa, Haraççioğlu MS 1177,4 are unique copies of the minor auxiliary tables [3] and [4], respectively.)

The first two sets of tables correspond to those in the large corpus of spherical astronomical tables computed for

Cairo that are generally attributed to the 10th-century Egyptian astronomer **Ibn Yūnus**.

Khalīlī's fifth set of tables was designed to solve all the standard problems of spherical astronomy, and they are particularly useful for those problems that, in modern terms, involve the use of the cosine rule for spherical triangles. Khalīlī tabulated three functions and gave detailed instructions for their application. The functions are the following:

$$f_\phi = \sin\theta / \cos\phi \text{ and } g_\phi = \sin\theta \tan\phi,$$

$$K(x,y) = \text{arc}\cos\{x/\cos y\},$$

computed for appropriate domains. The entries in these tables, which number over 13,000, were computed to two sexagesimal digits and are invariably accurate. An example of the use of these functions is the rule outlined by Khalīlī for finding the hour angle t for given solar or stellar altitude h, declination δ, and terrestrial latitude φ. This may be represented as:

$$t(h,\delta,\phi) = K\{[f_\phi(h) - g_\phi(\delta)],\delta\},$$

and it is not difficult to show the equivalence of Khalīlī's rule to the modern formula

$$t = \text{arc}\cos\{[\sin h - \sin\delta \sin\phi] / [\cos\delta \cos\phi]\}\ .$$

These auxiliary tables were used for several centuries in Damascus, Cairo, and Istanbul, the three main centers of astronomical timekeeping in the Muslim world. They were first described in 1973. In 1991 Glen Van Brummelen, in his statistical investigation of the errors in the entries, determined that the tables of (7) had been computed first and the tables of (6) were computed from these. In 2000, the fourth set of Khalīlī's tables was discovered in a manuscript in Bursa. These were compiled before the fifth set and also contain a set of tables of (7); when compiling his main set (5), Khalīlī simply took over the tables of (7) from this earlier set (4). So Van Brummelen's hypothesis was confirmed.

Khalīlī's computational ability is best revealed by his *qibla* table. The determination of the *qibla* for a given locality is one of the most complicated problems of medieval Islamic trigonometry. If (L,φ) and (LM,φ_M) represent the longitude and latitude of a given locality and of Mecca, respectively, and $\Delta L = |L - LM|$, then the modern formula for $q(L,\varphi)$, the direction of Mecca for the locality, measured from the south, is

$$q = \text{arc}\cot\{[\sin\phi\cos\Delta L - \cos\phi\tan\phi_M] / \sin\Delta L\}.$$

Khalīlī computed $q(L,\varphi)$ to two sexagesimal digits for the domains φ = 10°, 11°,..., 56° and ΔL = 1°, 2°,..., 60°; the vast majority of the 2,880 entries are either accurately computed or in error by ±1′ or ± 2′. Several other *qibla* tables based on approximate formulas are known from the medieval period. Khalīlī's splendid *qibla* table does not appear to have been widely used by later Muslim astronomers.

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