NAZARİYAT
Journal for the History of Islamic Philosophy and Sciences

Conquering the Time: An Example of a Manual for Making an Astrolabe Quadrant: Muḥammad Qunawī's *Hadiyyat al-mulūk*

Taha Yasin Arslan[*]

Abstract: Perhaps the most fruitful and valuable outcome of the advancements in astronomy that occurred in the Muslim world is the extraordinary development of instrumentation. With the application of trigonometry on a higher level and more accurate than ever before, Muslim astronomers developed new devices and techniques. One of these first-of-its-kind devices is the astrolabe quadrant, which is a simpler and easier-to-use version of the astrolabe. This instrument, albeit less accurate than the large-scale ones, is quite practical since it has all the markings of an astrolabe's front and *rete*, only inside a quarter of a circle. This small and portable device can be used by anyone who has a basic knowledge of astronomy and a simple user manual. It became popular specifically among those astronomers who worked on timekeeping. Although it is a very popular instrument, manuals for making it are quite rare. Muḥammad ibn Kātib Sīnān al-Qunawī al-Muwaqqit (d. c. 1524), one of the most important Ottoman astronomers in this regard, wrote two treatises on how to make an astrolabe quadrant: *Hadiyyat al-Mulūk* and *Risala fī ma‘rifat waḍ‘ al-rub‘ al-dāirat al-mawḍu‘ ‘ala al-muqanṭarāt*. Both of these treatises are the earliest manuals in Turkish for making this instrument. This article aims to introduce manuals for instrument-making via the example of Qunawī's detailed explanatory remarks in his *Hadiyyat al-Mulūk*. It follows his instructions step by step and uses his tables. At the end of the article is an astrolabe quadrant drawn according to his instructions. For more comprehensive studies, the transliteration of the treatise is attached in the appendix.

Keywords: Muḥammad ibn Kātib Sīnān al-Qunawī al-Muwaqqit, *rub‘ al-muqanṭarāt*, astrolabe quadrant, Ottoman astronomy, astronomical instruments, *‘ilm al-mīqāt*.

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DOI dx.doi.org/10.12658/Nazariyat.2.4.M0026

Atıf© Arslan, Taha Yasin, "Conquering the Time: An Example of a Manual for Making an Astrolabe Quadrant: Muḥammad Qunawī's Hadiyyat al-mulūk", *Nazariyat Journal for the History of Islamic Philosophy and Sciences* 2/4 (May 2016): 97-120

One of the most solid pieces of evidence of astronomical advancement in the Muslim world is the rich collection of astronomical instruments. The instrumentation begins with the reception of astronomical knowledge via the translation movement that occurred during the 8th and 9th centuries, when the Muslim world first came into contact with such classical Greek instruments as armillary spheres, plane astrolabes, and sundials. With the ensuing great advancements in mathematics, Muslims began learning how to design new, precise, and multi-tasking devices 9th century onwards. By the 14th and 15th centuries, many different types of instruments, among them the *al-rubʿ al-dāira* and the astrolabe, were popular and instrumentation itself had reached the stage of maturity. This period of mastery provides valuable anecdotes about the development of mathematical sciences and the process of craftsmanship in terms of wood, metal, and ivory. While the location of where the instrument was produced indicates the level and focus point of astronomical knowledge attained in the area, the preciseness of its markings makes assumptions possible about the markings' mathematical foundations and the quality of the craftsmanship.

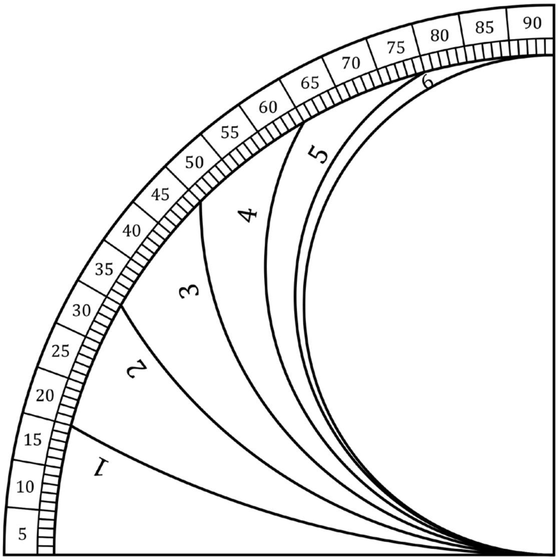

Figure 1. Drawing of a *al-rubʿ* with a 90-degree scale and seasonal hours according to the description given by Muḥammad ibn Aḥmad ibn Yusūf al-Khwārizmī.

As far as we know, the oldest historical record on the *al-rubʿ al-dāira* is found in Muḥammad ibn Aḥmad al-Khwārizmī's (d. 997) *Miftāḥ al-ʿulūm*, which mentions it as an instrument: which is named *al-rubʿ* and is different than the astrolabe, and shaped like the quarter of a circle and is used to measure the altitude and determine the time.[1] Although there is no detailed description, one can assume that it had a 90-degree scale and markings for the seasonal hours (see Figure 1).[2] Al-Khwārizmī

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[1] Muḥammad ibn Aḥmad ibn Yusūf al-Khwārizmī, *Miftāḥ al-ʿulūm*, ed. Ibrahim el-Ebyârî (Beyrut: Dār al-Kitāb al-ʿArabī, 2. Edition, 1989), 253.

[2] All drawings in this article are made by the author.

distinguishes this instrument from an astrolabe because of its markings, but the same markings, a 90-degree scale and seasonal hour curves, were commonly found on the back of astrolabes. Traditionally the back of an astrolabe is divided into four quadrants, each of which may contain different curves and scales such as an altitude scale, shadow square, tangent scale, sine graph, curves for the Sun's mean altitude on meridian, and calendars. Makers can choose from these scales, depending upon the instrument's purpose. Over the centuries, *al-rubʿ* has evolved from a basic altitude-measuring device, as Khwarizmī described, to a sophisticated analogue computer that has all of the features of an astrolabe mentioned above in the 13th century.[3]

Rubʿ al-muqanṭarāt

Al-Rubʿ is made of wood, copper, brass, bronze, or ivory and constructed by drawing, punching, or engraving. It has two faces used for observation and calculation: *rubʿ al-mujayyab* and *rubʿ al-muqanṭarāt*. Although they can be made separately, they are almost always made in pairs on two sides of the instrument, called *al-rubʿ* or *al-rubʿ al-dāira*.

On the reverse, namely the *rubʿ al-mujayyab* or the *rubʿ al-dustūr*, is a sine graph which is used to make trigonometrical calculations without the benefit of a pencil or paper. It consists of a graph with lines that are parallel, both horizontally and vertically, for each degree on a 60-degree scale. The arc of the *rubʿ al-mujayyab* contains a 90-degree scale. One can use *rubʿ al-mujayyab* to solve trigonometrical problems as easy as conversion of sine, cosine, and tangent or as hard as finding the *qibla* (the direction of Mecca) with the help of a manual.

Astronomers designed several versions of the *mujayyab* in order to increase the precision of their calculations and to solve more complex problems. 13th-century Mamluk astronomer Abū ʿAlī al-Ḥasan al-Marrākushī's[4] semi-circular instrument *dustūr* and another Mamluk astronomer Ibn al-Shāṭir's (d. 1375) triangular-shaped *rubʿ al-tām* and square-shaped *murabbaʿ* are good examples of the variety and advancements achieved in instrumentation.

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[3] In *Rubu Tahtası*, Muammer Dizer introduces this instrument as a derivation of much older instrument called *libna* which is used to measure the altitude. See Muammer Dizer, Rubu Tahtası (İstanbul: Boğaziçi Üniversitesi Matbaası, 1987), 6-7. His thought for the resemblance is based on only the altitude scale but same scales are also common for astrolabes as well.

[4] François Charette, "Marrākushī: Sharaf al-Dīn Abū ʿAlī al-Ḥasan ibn ʿAlī ibn ʿUmar al-Marrākushī," *The Biographical Encyclopedia of Astronomers (BEA)*, ed. Thomas Hockey et al. (New York: Springer, 2007), 739-740.

On the *obverse,* namely the *rubʿ al-muqanṭarāt*, is a stereographic projection of the sky which is a two-dimensional representation of celestial globe by dividing it with imaginary circles from the point of view of the southern celestial pole. *Rubʿ al-muqanṭarāt* carries curves, circles, and scales that are the same with those found on the front of an astrolabe, its disks, and the *rete*. All markings are folded into four in order to fit inside the quadrant. Other than almucantars, several markings such as azimuths, curves for the afternoon and the morning prayers, and 90-degree altitude scales are engraved as essentials.

Rubʿ al-muqanṭarāt can be used to measure the altitude of celestial objects as well as to determine the prayer times or find the *qibla*. The measurements made with it, albeit not very precise, are usually regarded as sufficient for regulating the prayer times. The difference between an astrolabe and a *rubʿ al-muqanṭarāt* is that the latter is easier to use since it does not require any complex procedures to operate and is often used to make observations only of the Sun. This device's user-friendly features, along with easy-to-read manuals, allow anyone with basic astronomical knowledge to operate it. Therefore, it has become quite popular among *muwaqqit*s (timekeepers) and *muadhdhin*s who deal with daily religious practices. Although it is no substitute for either the enormous instruments of observatories for precision or the astrolabes for multi-tasking, it is widely used in timekeeping that requires precision only in terms of minutes and thus is usually identified with timekeeping (*ʿilm al-mīqāt*). This relation between the *rubʿ al-muqanṭarāt* and timekeeping can be seen in the fact that it was developed by Mamluk astronomers, who specialized in timekeeping, instead of in Andalusia, Iran, or Transoxiana, where astrolabes were preferred.[5]

With the establishment of observatories and the office of *muwaqqit*, technical knowledge became essential for making instruments. Consequently, astronomers produced ample resources for both making and using them. Undoubtedly the most popular book in this regard is Marrākushī's two-volume *Jāmiʿ al-mabādī waʾl-ghāyāt fī ʿilm al-mīqāt*. This book, which is known in every corner of the Muslim world, begins by introducing calendars, spherical trigonometry, projections, and methods for determining the prayer times. For the very first time, he also provides his commonly used formulas. The book deals mainly with how to make numerous practical instruments like astrolabes, sundials, and *mujayyab*s, as well as the several enormous ones used in observatories, such as the armillary sphere (*dhāt al-khalāḳ*) and sextant (*sudus al-fakhrī*). Marrākushī describes the theoretical and technical

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[5] For the most extensive study on Mamluk astronomers and their works See. David A. King, *In Synchrony with the Heavens Studies in Astronomical Timekeeping and Instrumentation in Medieval Islamic Civilization: Volume 1, The Call of the Muezzin* (Leiden: Brill, 2004); Volume 2, *Instruments of Mass Calculation* (Leiden: Brill, 2005).

details of instrument making, draws them in accordance with his own descriptions, and then explains how to use them in easy-to-understand language.

His efficient use of intelligible language and depictions of the instruments make *Jāmiʿ al-mabādī* the most famous and popular book of its kind. It fulfils the need for such manuals, but with one exception: the lack of any description and information about the *rubʿ al-muqanṭarāt*. This void was filled shortly by another Mamluk astronomer: Najm al-Dīn al-Miṣrī (14th century). Science historian François Charette attributes an untitled work, which describes how to make more than one hundred instruments including different types of *rubʿ al-muqanṭarāt*, to him.[6] Unfortunately, this precious work never became as famous as Marrākushī's *Jāmiʿ al-mabādī*. The only other popular book on instrument making is Abū al-Rayḥān al-Bīrūnī's *Kitāb al-Istiʿāb fī sināʿat al-asṭurlāb*, which deals with constructing different and rather unusual types of astrolabes as well as a mechanical lunar calendar. Its tables for astrolabe construction were also used as a reference for making *rubʿ al-muqanṭarāts* as well.

The Ottoman Reception

By the end of 15th-century, the Ottomans were already familiar with both works. *Jāmiʿ al-mabādī*'s two copies (Suleymaniye Ayasofya 2669 and Topkapi Ahmed III, 3343) and *Kitāb al-Istiʿāb*'s one copy (Suleymaniye Ayasofya 2576) bear the stamp of Sultan Bayezid II. A note on the Ahmed III copy of *Jāmiʿ al-mabādī* indicates that this book was in the possession of Sultan Muḥammad II. Both works are also listed in *Daftar-i Kutub,* which contains a bibliographical record of Bayezid II's library.[7] With the proliferation of timekeeping practices at the end of 15th century, the Ottomans began preferring the *rubʿ al-muqanṭarāt*, which is called *rubu tahtası* in Ottoman Turkish. Ottoman quadrants have a unique character, since they were almost made of wood. This is also one of the reasons for their popularity, for drawing on wood, as opposed to engraving on brass or copper, is rather easy. One can use ink and a pen to put the markings either directly on the wooden surface or on a thin piece of paper that will later on be adhered and lacquered. Both methods, particularly the latter, reduce the risk of making an irretrievable mistake. The only downside of this method is that the drawings are not as long-lasting as are the engravings on metal or ivory. Due to various reasons such as lacquer's removal over time, the

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[6] For Charette's detailed study on the book see. François Charette, *Mathematical Instrumentation in Fourteenth-Century Egypt and Syria: The Illustrated Treatise of Najm al-Din al-Misri*, (Boston: Brill, 2003).

[7] See *Daftar-i Kutub's* copy Magyar Tudomanyos Akademia Künyvtara Keleti Gyüjtement, Török F.59, *riyāḍiyāt*, fol. 156a for *Cāmiʿu'l-mebādī* and fol. 157a for *Kitābu'l-İstiʿāb*.

ink's corrosion, or the wood's deterioration, most Ottoman quadrants had a short lifespan. Therefore, only a handful of them have survived until our time.

Astrolabe quadrants were essential devices for the timekeeper's quarters (*muwaqqitkhāna*), which was established in the second part of the 15th century.[8] Due to its increased use, many manuals for *rubʿ al-muqanṭarāt* and *rubʿ al-mujayyab* were written.[9] While there may have been a large number of user manuals, there were only few manuals for instrument making, particularly as regards *rubʿ al-muqanṭarāt*s. Muḥammad ibn Kātib Sīnān, who discerned this omission, wrote two treatises on making of astrolabe quadrant: *Hadiyyat al-mulūk* and *Risala fī maʿrifat waḍʿ al-dāirat al-rubʿ mawḍūʿ ʿala al-muqanṭarāt*.

Muḥammad Qunawī

As stated above, Ottoman timekeeping flourished during the second half of the 15th century due to the availability of copies of Mamluk astronomers' works from 13th-15th centuries. This process began with a corpus[10] of copied treatises composed by the copyist, astronomer, and astrolabe maker Omar al-Dimashqī (15th century), a student of ʿAlī al-Qushjī.[11] The timekeeping tradition then gained ground with Qunawī's works. Muḥammad Qunawī, who lived during the reigns of sultans Bayezid II, Selim I, and Suleyman I, worked as a *muwaqqit* in several mosques in Edirne and Istanbul.[12] He wrote 13 treatises, all on timekeeping. He continued the tradition of Mamluk astronomers and single-handedly pioneered Ottoman timekeeping.

He wrote nine of his works in very plain Turkish and often provided examples for the latitudes of Edirne and Istanbul. A quick inquiry into his works indicates that he is basically a member of Mamluk timekeeping tradition. In fact, he prefers using information from Mamluk works whenever possible and writes specifically on subjects that are not treated therein, thus leaving no stones unturned in timekeeping. For instance, instead of preparing tables for timekeeping by the Sun's position, he takes advantage of the 14th-century Mamluk astronomer Shams al-Dīn al-Khalīlī's extensive tables. On the other hand, he did compile the *Mīzān al-kawākib*,[13] which contains tables with approximately 250,000 numerical values and

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[8] For the list of instruments in timekeeper's quarters see. Süheyl Ünver, "Osmanlı Türkleri İlim Tarihinde Muvakkithaneler," *Atatürk Konferansları V 1971-72* (Ankara: Türk Tarih Kurumu, 1975), 254-257.

[9] Cevat İzgi, *Osmanlı Medreselerinde İlim*, 2 Volumes, (İstanbul: İz Yayıncılık, 1997), Volume 1, 428-448.

[10] Süleymaniye Library, Hamidiye 1453.

[11] İhsan Fazlıoğlu, "Qūshjī: Abū al-Qāsim ʿAlāʾ al-Dīn ʿAlī ibn Muḥammad Qushči-zāde," *The Biographical Encyclopedia of Astronomers (BEA)*, ed. Thomas Hockey et al. (New York: Springer, 2007), 946-948.

[12] İhsan Fazlıoğlu, "Qunawī: Muḥammad ibn al-Kātib Sīnān al-Qunawī," *The Biographical Encyclopedia of Astronomers (BEA)*, ed. Thomas Hockey et al. (New York: Springer, 2007), 945-946.

[13] For the content of the book and how to use its tables, see. Taha Yasin Arslan, "Osmanlıların Mîkât İlmine Katkıları: Mîzânü'l-kevâkib Örneği." *Osmanlı'da İlim ve Fikir Dünyası: İstanbul'un Fethinden Sü-*

is the first extensive work to deal with timekeeping by the stars' positions. In fact, it is the most genuine Ottoman contribution to timekeeping. Qunawī's two works on the astrolabe quadrant, both of which were mentioned above, are also important additions to this literature. Both treatises, particularly *Hadiyyat al-mulūk* with its 25 extant copies,[14] some of which are from 19th century, were used as references on instrumentation for centuries. As far as our inquiry goes, these two treatises are the earliest works in Ottoman Turkish on instrument making.[15]

Astronomers who specialized in timekeeping tend to make copies of extant and competent treatises, instead of compiling new ones, with the rare exception of preparing up-to-date tables by using new parameters. The Ottomans were no different, for they preferred to make copies of *Hadiyyat al-mulūk* and similar works instead of compiling new ones. Most of this treatise's extant copies date from the 17th century onward, a reality that indicates Qunawī's long-lasting authority on making astrolabe quadrants.

Hadiyyat al-mulūk

Although the work is not dated, it was clearly compiled before 1512 since it is dedicated to Sultan Bayezid II, as indicated on the text.[16] At the same era, the Ottomans benefited from Ali Qushji's and his students' works on theoretical astronomy, produced great astronomers like Mīrim Chelebī[17] and had already established the office of *muwaqqit*. *Hadiyyat al-mulūk* proves that the Ottomans were not just copyists of timekeeping knowledge, but rather that they first learned it and then improved upon it. The treatise was written out of necessity after the office of *muwaqqit* and the timekeeper's quarters were established. Qunawī is indeed aware that the people who deal with timekeeping are not specialized on astronomy; thus, he uses such simple mathematical equations that even people with limited technical knowledge can determine the time. He uses very plain language and gives examples

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leymaniye Medreselerinin Kuruluşuna Kadar, ed. Ömer Mahir Alper, Müstakim Arıcı (İstanbul: Klasik Yayınları, 2015), 251-261.

[14] For the copy records see. *Osmanlı Astronomi Literatürü Tarihi (OALT)*, 2 volumes, ed. Ekmeleddin İhsanoğlu. et al., (İstanbul: IRCICA 1997), volume 1, 86.

[15] Another example for the manuals for instrument making in the Ottoman literature besides Qunawī's works is *Rubu Dâirenin Esâsı ve Usûl-i Tersîmi* which was written by Ahmed Ziya Akbulut (d.1938) who was the last *muwaqqit* in the empire and the first *Baş Muvakkit* in the new-born Republic of Turkey. This work is published with a transliteration to modern Turkish by M. Şinasi Acar, Atilla Bir and Mustafa Kaçar in 2014. See. M. Şinasi Acar, Atilla Bir, and Mustafa Kaçar, *Rubu Tahtası Yapım Kılavuzu*, İstanbul: Ofset Yapımevi Yayınları, 2014.

[16] Fol. 13b.

[17] İhsan Fazlıoğlu, "Mīram Čelebī: Maḥmūd ibn Quṭb al-Dīn Muḥammad ibn Muḥammad ibn Mūsā Qāḍīzāde," *The Biographical Encyclopedia of Astronomers (BEA)*, ed. Thomas Hockey et al. (New York: Springer, 2007), 788-789.

for every new subject that he presents.

Hadiyyat al-mulūk (*A Present to Sultans*) provides adequate information on how to make an astrolabe quadrant for anyone who has a basic knowledge of astronomy. In the introduction,[18] Qunawī points out that "*āfāqī muwaqqit*s must be able to make an astrolabe quadrant because they might require to make one if they relocate to another area with a different latitude," for the markings on the astrolabe quadrants are valid only for a specific latitude. Qunawī reveals his reasons for compiling this treatise: to solve this crucial problem and, of course, to have the privilege of securing an audience with the sultan. He also mentions why he only deals with the *rubʿ al-muqanṭarāt* side of the instrument and states that even though it is harder to make, it is easier to use, whereas the *rubʿ al-mujayyab* is easier to make but harder to use.

The work consists of 20 chapters and table of contents is shown below:

i. On constructing a true quadrant.
ii. On constructing a true quadrant with a different method.
iii. On constructing a true quadrant with another different method.
iv. On constructing the ratio scale along the radius of the quadrant
v. On constructing the ratio scale along the radius of the quadrant with a different method.
vi. On constructing the equator.
vii. On constructing the Tropic of Cancer.
viii. On deriving a table of almucantars from the table of radiuses.
ix. On constructing almucantars.
x. On constructing the curve for the first afternoon prayer.
xi. On constructing the curve for the second afternoon prayer.
xii. On constructing the curve for evening twilight.
xiii. On constructing the curve for the second daybreak.
xiv. On constructing the arc of the southern zodiac signs
xv. On constructing the arc of the northern zodiac signs.
xvi. On dividing the southern and northern zodiac signs with respect to their right ascensions.
xvii. On finding the locations of the zenith, the centre of the first azimuth, and the distance between the apex of the quadrant and the centre of the first azimuth.

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[18] Fol. 13b.

xviii. On finding the location of zenith with a different method.

xix. On constructing a new ratio scale along the radius of the first azimuth and extending it through the additional piece as long as it can fit 342 degrees and 58 minutes.

xx. On constructing azimuths with the help of the new ratio scale.

The first three chapters deal with constructing the instrument's outer frame and verifying its accuracy. According to the first and the second chapters, the very first step of making an astrolabe quadrant is to construct two lines equal in length and perpendicular to each other while joining at their end. The point of join becomes the apex of the quadrant upon which the calculations for all of the markings are based. The line siding with the sighting units (*hadafa*) is the midday line, and the other one is the east-west line. Qunawī only mentions these sighting units' names. In the Ottoman tradition of astrolabe quadrants, these are constructed parallel to the side of the instrument as two level ledges (see Figure 4) and used to measure the altitude of celestial objects. We can assume that Qunawī did not want to restrict the readers to only one method, for sighting units can be constructed in different forms.

Once perpendicular lines are constructed and the apex of the quadrant is ascertained, a compass with a needle fixed to the apex is used to construct an arc from one open end of the lines to the other, thereby forming the arc of the Tropic of Capricorn. Another and larger arc that runs parallel to the Tropic of Capricorn is constructed by adjusting the legs of the compass while its needle remains fixed. The space between the two arcs is turned into a 90-degree scale divided into 5 degrees and subdivided into 1 degree and every 5 degrees is labelled with *abjad* notation. Here are the *abjad* equivalences of the degrees:

90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
ص	فه	ف	عه	ع	سه	س	نه	ن	مه	م	له	ل	كه	ك	يه	ي	ه

The third chapter deals with verifying the construction's accuracy. A line between two ends of the Tropic of Capricorn is constructed to form the hypotenuse of an isosceles triangle. Then one of the sides is divided into five equal units. If the hypotenuse measures 7 units in length, then the quadrant has been constructed accurately (see Figure 2). As a matter of fact, the hypotenuse of a 5-unit isosceles triangle is not 7 but 5√2, which is approximately 7.07 units. However, on an average-sized instrument, say with an 18-cm radius, a unit measures 3.6 cm. Therefore, Qunawī's error margin would be 2.252 mm (3.6*0.07), which is considered insignificant and therefore can be easily ignored.

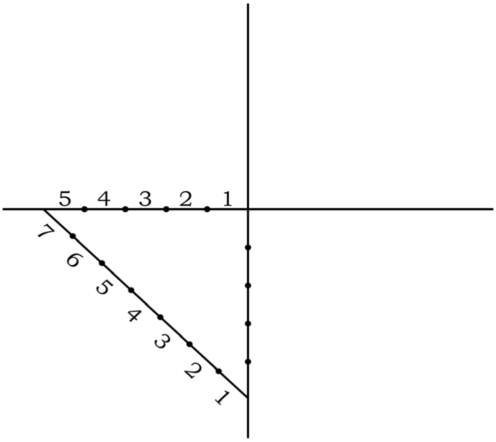

Figure 2. Showing the method to check the accuracy of constructed quadrant.

The fourth and the fifth chapters deal with the ratio scale used to calculate the dimensions of almost all circles and arcs. The ratio scale is equal to the radius of the instrument in length. It is divided into 15 equal divisions, each of which is one degree labelled with *abjad* notation. At this point, Qunawī gives two options: divide the divisions either into 6 to form 10-minute units or into 4 to form 15-minute units. He prefers the first one in his examples (see Figure 3). Therefore, values under 10 minutes are calculated approximately within the ratio scale. Dividing the divisions into lower values, such as 2 or 3 minutes, can cause some difficulties, such as the overlapping of very close lines. For example, the ratio scale of an instrument with 18-cm radius is also 18 cm. Each division is 1.2 cm, and the minutes are 2 mm apart. Therefore, 2 minute units would be 4 mm and 3 minute units would be 6 mm in length, which means the units would be too close to construct. Thus, using 20-mm long 10-minute units is more suitable and practical.

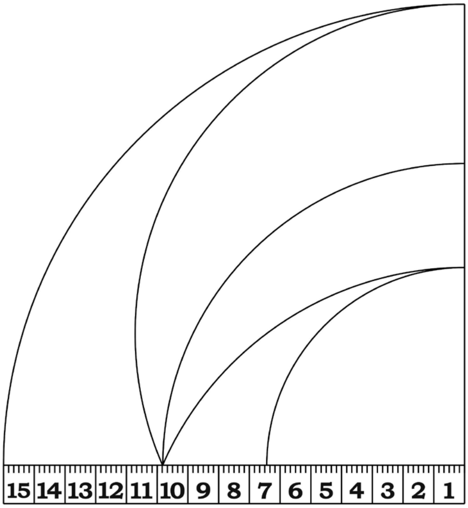

Figure 3. The ratio scale with a set of 1-degree divisions and 10-minute subdivisions.

For instance, measuring the length of 4 degree and 37 minutes on the ratio scale will be approximate. An estimated point is marked between the third and the fourth units, preferably a little bit closer to the fourth one in the fifth division; thus, the approximate length of the value 4 degrees 37 minutes is found. It is very common to ignore simple calculation errors when dealing with rather small and portable instruments, because the ratio scale is prepared separately for each new instrument in different sizes, and the precision of the scale depends upon the maker's skills.

Table 1
Numerical equivalences of the table of radiuses with abjad notation in the fol. 20a of Muḥammad Qunawī's Hadiyyat al-mulūk.

Radiuses	Magnitude	Radiuses	Magnitude	Radiuses	Magnitude	Radiuses	Magnitude	Radiuses	Magnitude	Radiuses	Magnitude
37° 59′	151	17° 22′	121	10° 00′	91	5° 47′	61	2° 43′	31	5′	1
39° 25′	152	17° 43′	122	10° 10′	92	5° 54′	62	2° 49′	32	10′	2
40° 35′	153	18° 05′	123	10° 21′	93	6° 01′	63	2° 54′	33	15′	3
42° 33′	154	18° 23′	124	10° 32′	94	6° 08′	64	3° 00′	34	20′	4
44° 19′	155	18° 52′	125	10° 43′	95	6° 15′	65	3° 06′	35	25′	5
46° 43′	156	19° 17′	126	10° 54′	96	6° 23′	66	3° 11′	36	31′	6
48° 17′	157	19° 42′	127	11° 06′	97	6° 30′	67	3° 17′	37	36′	7
50° 33′	158	20° 08′	128	11° 18′	98	6° 38′	68	3° 23′	38	41′	8
53° 01′	159	20° 36′	129	11° 30′	99	6° 45′	69	3° 28′	39	46′	9
55° 43′	160	21° 03′	130	11° 42′	100	6° 53′	70	3° 34′	40	51′	10
58° 43′	161	21° 33′	131	11° 55′	101	7° 00′	71	3° 40′	41	57′	11
60° 02′	162	22° 04′	132	12° 08′	102	7° 08′	72	3° 46′	42	1° 02′	12
65° 59′	163	22° 36′	133	12° 21′	103	7° 16′	73	3° 52′	43	1° 07′	13
69° 55′	164	23° 09′	134	12° 35′	104	7° 24′	74	3° 53′	44	1° 12′	14
74° 37′	165	23° 43′	135	12° 48′	105	7° 32′	75	4° 05′	45	1° 17′	15
80° 03′	166	24° 19′	136	13° 02′	106	7° 40′	76	4° 10′	46	1° 23′	16
86° 14′	167	24° 57′	137	13° 17′	107	7° 49′	77	4° 16′	47	1° 28′	17
93° 29′	168	25° 35′	138	13° 31′	108	7° 57′	78	4° 22′	48	1° 33′	18
102° 01′	169	25° 16′	139	13° 46′	109	8° 06′	79	4° 28′	49	1° 38′	19
112° 20′	170	26° 59′	140	14° 02′	110	8° 14′	80	4° 34′	50	1° 44′	20
134° 51′	171	27° 44′	141	14° 18′	111	8° 23′	81	4° 41′	51	1° 49′	21
140° 31′	172	28° 31′	142	14° 34′	112	8° 32′	82	4° 46′	52	1° 54′	22
160° 54′	173	29° 21′	143	14° 50′	113	8° 41′	83	4° 54′	53	2° 00′	23
180° 31′	174	30° 54′	144	15° 07′	114	8° 50′	84	5° 00′	54	2° 05′	24
225° 01′	175	31° 10′	145	15° 25′	115	9° 00′	85	5° 07′	55	2° 10′	25
281° 26′	176	32° 08′	146	15° 48′	116	9° 09′	86	5° 13′	56	2° 16′	26
375° 14′	177	33° 10′	147	16° 02′	117	9° 19′	87	5° 20′	57	2° 21′	27
575° 21′	178	34° 16′	148	16° 21′	118	9° 29′	88	5° 26′	58	2° 26′	28
1132° 26′	179	35° 25′	149	16° 50′	119	9° 39′	89	5° 33′	59	2° 32′	29
0	180	36° 40′	150	17° 01′	120	9° 49′	90	5° 40′	60	2° 38′	30

In the sixth and seventh chapters, Qunawī describes how to construct the Tropic of Cancer and the celestial equator using the ratio scale. In this phase, he mentions a "table of radiuses" scale for the first time. This table, which consists of numerical values in degrees and minutes for each degree from 1 to 180 (see Table 1), is used to calculate the radiuses of almucantars for every latitude. It can also be prepared for every half degree to fit any locality, such as Mecca, 21 degrees 30 minutes or Damascus, 33 degrees 30 minutes. In fact, one copy of this treatise has a table of radiuses for every half degree (Süleymaniye Library Hüsrev Paşa 236).

Qunawī does not mention whether he prepared the tables or which formulas were used to prepare it, or if it is an extract what its source is. These oversights prevent a detailed inquiry into the technical background of the numerical values. The absence of the original manuscript makes it harder to detect any error and to discuss the accuracy of the values in the extant copies. However, striking similarities between Qunawī's table and Bīrūnī's table of radiuses in his *Kitāb al-Istiʿāb* (Suleymaniye, Carullah 1451 fol. 22a) makes us think that Qunawī might have copied his table from Bīrūnī's work.[19]

Qunawī uses the entry for 90 degrees on the table of diameters as the value of the celestial equator, and 66 degrees as the value of the Tropic of Cancer. This '66 degrees' is an approximate value of the complementary angle of ecliptic value of 23 degrees 30 minutes. The value of the equator is extracted as 9 degrees 49 minutes. A compass is adjusted to the length of this value on the ratio scale and then used to construct an arc on the instrument, while its needle is fixed at the apex of the quadrant. The operation is repeated for the Tropic of Cancer, with its own value of 6 degrees 23 minutes.

The eighth chapter deals with how to create a table for a specific latitude that gives values for diameters and radiuses of the almucantar, and the distance between the centres of almucantars and the apex of the quadrant. It is quite easy for a person who can manage simple four operations. Qunawī presents two pre-prepared tables of radiuses, one for the latitude of Edirne, 42 degrees and another for the latitude of Istanbul, 41 degrees and uses the former in his example of preparing the almucantar table.

Almucantar tables have six columns. The degrees of almucantars are written top down from 0 to 90 at the rightmost column and can be written according to the intervals of almucantars (e.g., 0, 1, 2, 3 … 90 or 0, 2, 4, 6 … 90). Qunawī prepares his tables for each 2-degree almucantars in accordance with the tradition of instrument

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[19] We haven't come across any published work on Bīrūnī's table of radiuses. We will be investigating this table in our forthcoming study.

making in the Muslim world. Two numerical values are extracted from the table of radiuses and entered into the second and the third columns, entitled "the first record" (*maḥfūẓ al-awwal*) and "the second record" (*maḥfūẓ al-s̱ānī*), respectively. The diameters and distances are calculated from these entries. The fourth column from the right gives the value of diameters of almucantars; the fifth column is for the radiuses, and the sixth is for the distances between the centres of almucantars and the apex of the quadrant on the positive y-axis. All of the values given in degrees and minutes in the sexagesimal system are units for the ratio scales. Qunawī's detailed instructions for creating a table of almucantars for 42-degree latitude are presented below:

i. Write down the numbers from 0 to 90 at 2 degree intervals.

ii. Find the entry for 42 degrees as 3 degrees and 46 minutes in the table of radiuses. Enter the value into the second column as "the first record" of 0-degree almucantar. Henceforth "the first record" of each almucantars is extracted from the table of radiuses ascending from 42. Since the table of almucantars is prepared for 2 degree intervals, the next entry is for a 2-degree almucantar, and its value is extracted from the entry for 40 degrees as 3 degrees and 34 minutes. This operation is repeated until it reaches the related latitude. Once the number of the almucantar is the same as that of the latitude, the table of radiuses ascends to 0 degrees. But there is no entry for 0, and thus the value for a 42-degree almucantar is zero. For a larger number of almucantars, the entries in the table of radiuses are extracted top down starting from 2 for 44, 4 for 46, and so on. Once it reaches 48 degrees, which is the complementary angle of the related latitude 42, the entry for 90-degree almucantar is extracted. In this case, the value is 4 degrees and 22 minutes.

iii. The extracting method for "the second record" is quite similar to "the first record's." The only difference is that the value for a 0-degree almucantar is extracted as the entry of the latitude's supplementary angle, instead of the latitude itself. To find "the second record," first 138 is obtained by extracting 42 from 180. The entry for 138 in the table of radiuses is "the second record" value for a 0-degree almucantar. Similar to "the first record" for every larger number of the almucantar, the entry for a lower number is extracted from the table of radiuses. For example, the value for a 2-degree almucantar is the entry of 136 degrees, and for a 4-degree almucantar it is the entry of 134 degrees. Since there cannot be any latitude higher than 90 degrees, the supplementary of latitudes cannot be lower than 90 degrees. Therefore, the entries are always higher than zero and there is no need for an inverted operation, as it is done for "the first record." In the pre-prepared table for 42-degree latitude, "the second record" value for a 90-degree almucantar is 4 degrees 22 minutes, the same as for "the first record." This indicates that the extraction is correct, as both records are supposed to have the same value.

iv. Once "the first record" and "the second record" are obtained, there is no need to go back to the table of radiuses, for these two simple operations give the diameters of all almucantars. Almucantars between 0 degrees and the degree of the latitude, in this case 42, are calculated by adding "the second record" to the first. Almucantars larger than the latitude, that is, 44-90 degrees, are calculated by extracting "the first record" from "the second record."

v. Values for the radiuses are obtained by simply dividing the diameters in half. However, if the result is not a whole number, the half of a minute is ignored. For example, the diameter of a 30-degree almucantar for a 42-degree latitude is 14 degrees and 33 minutes, and its radius is 7 degrees 16 minutes 30 seconds. The seconds are ignored, and the value is given as 7 degrees and 16 minutes.

vi. The value in the sixth column gives the distance between the centres of almucantars and the apex of the quadrant on the positive y-axis. It is obtained by extracting "the first record" from the radius of the almucantar.

The calculations mentioned above are shown here, such as:

For the first record

$$a_n = \begin{cases} k_{\varphi - n} & n < \varphi \\ k_{n-\varphi} & n > \varphi \\ 0 & n = \varphi \end{cases} \qquad (1)$$

is used, and for the second record

$$b_n = k_{180-[\varphi + n]} \qquad (2)$$

is used. Once a_n and b_n are obtained, the diameters and radiuses of almucantars are extracted like so:

$$r_n = \begin{cases} a_n + b_n \\ b_n - a_n \end{cases} \qquad (3)$$

$$D_n = \frac{r_n}{2} \qquad (4)$$

The distance between the centres of almucantars and the apex on the positive y-axis can be found with this relation:

$$d_n = D_n - a_n \qquad (5)$$

ϕ the local latitude

a the first record

b the second record

D the diameter of the almucantar

r the radius of the almucantar

d the distance between the centre of the almucantar and the apex of the quadrant on the positive y-axis

k the coefficient in the table of radiuses

n the number of almucantars

$\varphi = 1, 2, 3, \ldots, 90$ and $n = 0, 2, 4, \ldots, 90$

The treatise's ninth chapter deals with how to construct almucantars by using a prepared table (see Table 2). Since all numerical values in the table of almucantars are units for the ratio scales, they can be used for instruments of any size. To find the true lengths of the values for a specific instrument, the values are measured on the ratio scale made for that instrument. For instance, a 0-degree almucantar's diameter reads 14 degrees and 40 minutes for a 42-degree latitude. This value is actually 14 degrees and 40 minutes of a 15-degree ratio scale. The needle of a compass is fixed at the beginning of the ratio scale, and its legs are opened until the pencil lead reaches the fourth ten-minute unit of the 15th degree division, which ensures that the true length is of the diameter is obtained. This can also be obtained by calculation: If the radius of the quadrant and the ratio scale is 18 cm, then one degree of the ratio scale is 1.2 cm and one minute is 2 mm. If so, 14 degrees and 40 minutes would be 17.6 m (14*1.2 + 40*0.02).

The length of the distance of the centre of an almucantar is measured on the ratio scale by using a compass. Compass legs are adjusted to the intended length by applying the value on the ratio scale. The needle of the compass is then fixed at the apex of the quadrant, and the compass is rotated until the pencil lead reaches the meridian line, where it is marked. This is the centre of that almucantar. Once this is done, the legs of the compass are readjusted to the length of the diameter of the almucantar. The needle is fixed at the centre of the almucantar, and the section of the almucantar that remains on the instrument is constructed as an arc. The whole operation is repeated for each almucantar, since all of them have different values for diameter and the distance.

Table 2.
A table of almucantar (fol. 19a) for 42-degree latitude is derived from *Hadiyyat al-mulūk*'s table of radiuses. Values written in abjad notation are converted to their numerical equivalences. Some calculation mistakes, most likely the copyist's, are spotted and corrected with the help of the table of radiuses. The corrected values are highlighted in the table above.

The Distance to the apex (on the y-axis)	Radius of Almucantar	Diameter of Almucantar	The Second Record	The First Record	Number of Almucantars		The Distance to the apex (on the y-axis)	Radius of Almucantar	Diameter of Almucantar	The Second Record	The First Record	Number of Almucantars
Total	One half	Subtrahend					Subtrahend	One half	Total			
5° 21′	5° 11′	10° 22′	10° 32′	10′	44		10° 54′	14° 40′	29° 21′	25° 35′	3° 46′	0
5° 15′	4° 55′	9° 50′	10° 10′	20′	46		10° 22′	13° 56′	27° 53′	24° 19′	3° 34′	2
5° 10′	4° 39′	9° 18′	9° 49′	31′	48		9° 53′	13° 16′	26° 32′	23° 09′	3° 23′	4
5° 05′	4° 24′	8° 48′	9° 29′	41′	50		9° 26′	12° 37′	25° 15′	22° 04′	3° 11′	6
5° 00′	4° 09′	8° 18′	9° 09′	51′	52		9° 01′	12° 01′	24° 03′	21° 03′	3° 00′	8
4° 56′	3° 54′	7° 48′	8° 50′	1° 02′	54		8° 39′	11° 28′	22° 57′	20° 08′	2° 49′	10
4° 52′	3° 40′	7° 20′	8° 32′	1° 12′	56		8° 19′	10° 57′	21° 55′	19° 17′	2° 38′	12
4° 48′	3° 25′	6° 51′	8° 14′	1° 23′	58		7° 58′	10° 24′	20° 49′	18° 23′	2° 26′	14
4° 44′	3° 11′	6° 22′	7° 57′	1° 33′	60		7° 43′	9° 59′	19° 59′	17° 43′	2° 16′	16
4° 42′	2° 58′	5° 56′	7° 40′	1° 44′	62		7° 28′	9° 33′	19° 06′	17° 01′	2° 05′	18
4° 39′	2° 45′	5° 30′	7° 24′	1° 54′	64		7° 13′	9° 07′	18° 15′	16° 21′	1° 54′	20
4° 36′	2° 31′	5° 03′	7° 08′	2° 05′	66		7° 02′	8° 46′	17° 32′	15° 48′	1° 44′	22
4° 34′	2° 18′	4° 37′	6° 53′	2° 16′	68		6° 47′	8° 20′	16° 40′	15° 07′	1° 33′	24
4° 32′	2° 06′	4° 12′	6° 38′	2° 26′	70		6° 35′	7° 58′	15° 57′	14° 34′	1° 23′	26
4° 30′	1° 52′	3° 45′	6° 23′	2° 38′	72		6° 25′	7° 37′	15° 14′	14° 02′	1° 12′	28
4° 28′	1° 39′	3° 19′	6° 08′	2° 49′	74		6° 14′	7° 16′	14° 33′	13° 31′	1° 02′	30
4° 27′	1° 27′	2° 54′	5° 54′	3° 00′	76		6° 05′	6° 56′	13° 53′	13° 02′	51′	32
4° 25′	1° 14′	2° 29′	5° 40′	3° 11′	78		5° 57′	6° 38′	13° 16′	12° 35′	41′	34
4° 24′	1° 01′	2° 03′	5° 26′	3° 23′	80		5° 48′	6° 19′	12° 39′	12° 08′	31′	36
4° 23′	49′	1° 39′	5° 13′	3° 34′	82		5° 41′	6° 01′	12° 02′	11° 42′	20′	38
4° 23′	37′	1° 14′	5° 00′	3° 46′	84		5° 34′	5° 44′	11° 28′	11° 18′	10′	40
4° 22′	24′	48′	4° 46′	3° 58′	86		5° 27′	5° 27′	10° 54′	10° 54′	0	42
4° 22′	12′	24′	4° 34′	4° 10′	88							
4° 22′	0	0	4° 22′	4° 22′	90							

Once the arcs are constructed, Muḥammad Qunawī describes how to construct the curves for the time of the first afternoon prayer (*ʿaṣr awwal*) and of the second afternoon prayer (*ʿaṣr s̱ānī*) in the 10th and 11th chapters. To be able to construct these curves, the Sun's meridian altitude at the beginning of the first and the second afternoon prayers at three dates (i.e., at the Tropic of Capricorn, at the equator, and at the Tropic of Cancer) are required. Qunawī gives no details about how to calculate these values. This may be because calculating these values is an entirely different topic in timekeeping, and thus he may have preferred to avoid going off subject. Instead, he advises the makers to consult a pre-prepared table entitled *ʿaṣr āfāqī*. The values extracted from that table are utilized as almucantar degrees and counted upwards from the 0-degree almucantar, which is the horizon. The intersection of related almucantar and the Tropic of Cancer is marked. The same operation is repeated for the intersections of the Tropic of Capricorn, the equator, and their respective almucantars. Once these three positions have been marked, they are interconnected by an arc that is the curve for the first afternoon prayer. If the values for the second afternoon prayer are used in the operation, the arc becomes the curve for the second afternoon prayer. Unfortunately, Qunawī does not provide an *ʿaṣr āfāqī* table. As far as we know he never prepared one; instead, he used Khalīlī's *Jadwal al-āfāqī* and translated it into Turkish as *Tarjuma-i Jadwal al-āfāqī*.

The 12th and 13th chapters deal with constructing the curves for the evening twilight (*al-shafaq*) and the daybreak (*al-fajr*). Once again Qunawī refers to tables that he did not provide. He uses 17 degrees below the horizon for twilight and 19 degrees below the horizon for daybreak as the Sun's altitude at the beginning of the intervals. The instructions for constructing the curves are as follows:

First the value of evening twilight at the Tropic of Cancer is obtained through the tables. Then a straight ruler is rotated while its one end is fixed at the apex. Once the other end reaches the obtained value on the altitude scale, the intersection of the ruler and the Tropic of Cancer is marked. This operation is repeated for the equator and the Tropic of Capricorn with their own values, and two more points are marked. The arc constructed from these three marks makes the curves for evening twilight, which is the beginning of the interval for the night prayer. If the whole operation is repeated with a minor change in the parameter of the Sun's altitude from 17 degrees to 19 degrees below the horizon, then the constructed arc becomes the curve for daybreak, which is the beginning of the interval for the morning prayer.

In the text, Qunawī gives the values for twilight of 42 degrees latitude as 32 degrees 12 minutes on the Tropic of Cancer, 33 degrees on the equator, and 35 degrees on the Tropic of Capricorn. In his example, a ruler with a fixed end at the apex is rotated to 32 degrees and 12 minutes on the altitude scale to mark the intersection of the ruler and the Tropic of Cancer. It is rotated to 33 degrees to mark the intersection of the ruler and the equator, and to 35 degrees to mark the intersection of the ruler and the Tropic of Capricorn. Then these three marks are interconnected by an arc to form the curve for twilight.

Chapters 14 to 16 deal with how to construct and divide the zodiac. Unlike the astrolabe, where the zodiac is represented as a full circle on the *rete*, the astrolabe quadrant neither has a *rete* nor is a full circle. Therefore, the zodiac is folded in four in order to fit on the instrument accurately, where it forms two eccentric arcs. The twelve signs are divided into two six-sign groups for each arc. The wider arc represents the southern zodiac signs, and the smaller one represents northern zodiac signs. Qunawī begins by constructing the zodiac arcs. The first step is to find the distance between the centre of the Tropic of Cancer and the apex of the quadrant, and then add 15 to that value. The true length of the new value is measured on the ratio scale by a compass. The needle is then fixed at the apex, and the compass is rotated to the meridian line. Wherever the pencil lead points is marked, then the needle is fixed at this mark. The legs of the compass are adjusted so that the pencil lead reaches the east-west point.[20] Once again, the compass is rotated to construct an arc through the instrument's surface until it reaches to the Tropic of Capricorn. This is the arc of the southern zodiac signs. The same method is used to construct the arc of northern zodiac signs. But this time, the centre of the arc is outside the instrument below the east-west line on the same axis with the meridian line.

To be able to construct it accurately, a piece of wood as thick as the quadrant and at least one hand-span wide is positioned below the side with the east-west line. After being temporarily fixed onto the instrument, the meridian line is extended on the wooden piece. This part of the line is called "the meridian line below the horizon". The distance between the centre of the arc of the southern zodiac signs and the apex is the same as the distance between the centre of the arc of the northern zodiac signs and the apex. However, as the distance for the northern zodiac signs is measured on the negative y-axis, it is on the meridian line below the horizon. Once the centre of the arc is located, the needle is fixed at it and the compass is rotated in order to construct the arc between the east-west point and the Tropic of Cancer. This is the arc of the northern zodiac signs.

Following the construction of the arcs, both are divided into its signs and subdivided into units. Since this operation requires very complicated trigonometric

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[20] The east-west point is the point where the 0-degree almucantar intersects with the east-west line (see Figure 4).

calculations, Qunawī provides a table of pre-calculated values that is valid for every latitude (see Table 3).[21] Although he gives these values in degrees, minutes and seconds, he uses only degrees in his examples. As can be seen from the table, each southern sign has the same value with a northern sign. For instance, the values for Libra, a southern sign, and Aries, a northern sign, are both 28 degrees. The values for Scorpio and Taurus are 58 degrees. The remainder of the arc, between 58 degrees and 90 degrees, are Sagittarius for southern and Gemini for northern.

The method of dividing the zodiac is the same as the method for constructing the curves of the evening twilight and daybreak. A ruler with a fixed end at the apex is rotated until the other end reaches the intended degree, in this case 28 degrees and 58 degrees, respectively, on the altitude scale. When the ruler is at the correct position, both arcs of the zodiac are marked with notches to symbolize the beginning and the end of the signs. This method is also used to subdivide each sign into two-degree intervals.

Table 3.
The numerical equivalences of the table of zodiac with abjad notation in fol. 25b.

Gemini	Degree of the sign	Taurus	Degree of the sign	Aries	Degree of the sign
Sagittarius		Scorpio		Libra	
Degree Minute Second		Degree Minute Second		Degree Minute Second	
59° 13′ 42″	2	29° 43′ 18″	2	1° 50′ 03″	2
61° 19′ 33″	4	31° 44′ 23″	4	3° 40′ 11″	4
64° 06′ 13″	6	33° 40′ 30″	6	5° 30′ 23″	6
66° 13′ 23″	8	35° 37′ 16″	8	7° 20′ 43″	8
68° 21′ 07″	10	37° 34′ 13″	10	9° 11′ 12″	10
70° 29′ 26″	12	39° 32′ 50″	12	11° 01′ 44″	12
72° 38′ 13″	14	41° 31′ 40″	14	12° 52′ 44″	14
74° 47′ 24″	16	43° 31′ 14″	16	14° 13′ 19″	16
77° 17′ 01″	18	45° 31′ 31″	18	16° 35′ 34″	18
79° 06′ 57″	20	47° 32′ 32″	20	18° 26′ 32″	20
81° 17′ 11″	22	49° 34′ 15″	22	20° 19′ 53″	22
83° 27′ 33″	24	51° 36′ 18″	24	22° 12′ 33″	24
85° 33′ 23″	26	53° 39′ 14″	26	24° 05′ 12″	26
87° 49′ 09″	28	55° 53′ 47″	28	25° 19′ 39″	28
90° 00′ 00″	30	57° 18′ 25″	30	27° 53′ 13″	30

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[21] For modern equivalences of these formulas see. Acar, Bir ve Kaçar, *Rubu Tahtası Yapım Kılavuzu*, 59-60; Morrison, James E., *The Astrolabe*, (Rehoboth Beach: Janus, 2007), 246-247.

Muḥammad Qunawī does not mention all of the twelve signs either in his examples or in the table, because each sign has an inverse couple. On the arc of the southern zodiac, signs read Libra, Scorpio, and Sagittarius, respectively, from the east-west point to the Tropic of Capricorn, and it reads Capricorn, Aquarius, and Pisces in reverse. Therefore, Libra-Pisces, Scorpio-Aquarius, and Sagittarius-Capricorn are inverse couples. On the arc of the northern zodiac, the signs read Aries-Virgo, Taurus-Leo, and Gemini-Cancer are thus inverse couples. The value of a degree of a sign is the same with the value that completes it to 30. For instance, the value for 10 degrees of a sign is the same as the value of 20 degrees of its couple.

The last four chapters of the treatise deal with how to construct azimuths. Qunawī begins with the method of finding the dimensions and the position of the first azimuth and zenith, as they are both references for constructing all azimuths, for the centres of all azimuths are aligned with the centre of the first azimuth on the x-axis. Therefore, the first thing is to find the position of the first azimuth, and then to measure the distances of the centres of the remaining azimuths. The required values needed to construct the first azimuth are extracted from the table of radiuses, just as it is done for almucantars. In the case of the azimuths, this is valid only for the first azimuth, which is the 0-degree azimuth.

The entry for the angle, which is supplementary to the local latitude, is extracted from the table of radiuses as “the first record” of the first azimuth. The entry for the complementary of the supplementary of the local latitude is extracted as “the second record.” The sum of the two records gives the diameter of the first azimuth. The first record is extracted from the radius to obtain the distance between the centre of the first azimuth and the apex of the quadrant on the negative y-axis.

The values for the diameter and the distance are enough to construct the first azimuth. The operation mentioned above can be shown like so:

The first record is extracted with the following relation:

$$a = k_{90-\varphi} \qquad (6)$$

For the diameter of the first azimuth, the following relation is used:

$$b = k_{180-[90-\varphi]} \qquad (7)$$

The diameter of almucantar is extracted from

$$D = z + t \qquad (8)$$

and by applying the relation of no. 5, the distance between the centre of the first azimuth and the apex of the quadrant on the negative y-axis can be obtained with:

$$d = \frac{D}{2} - z \qquad (9)$$

z the first record of the first azimuth
t the second record of the first azimuth
k the coefficient in the table of radiuses
D the diameter of the first azimuth
d the distance between the centre of the first azimuth and the apex of the quadrant on the negative y-axis.

To construct the first azimuth, a lengthy piece of wood as thick as the instrument is placed below the side with the east-west line. The centre of the first azimuth is then located and marked on this wooden piece. The needle of a compass is fixed at the centre of the first azimuth, and the legs are opened until the pencil lead reaches the east-west point. All parts of the first azimuth, meaning a full circle is constructed. The intersection of the meridian line and the azimuth is the local zenith. All azimuths must touch this point.

Table 4.
The numerical equivalences of the table of azimuths showing the distance between the centres of the azimuths and the centre of the first azimuth with abjad notation in fol. 27b.

Table of azimuths	
The Distance to the apex	Degrees of azimuths
Degree Minute	
2° 38′	5
5° 15′	10
8° 12′	15
10° 55′	20
13° 58′	25
17° 48′	30
21° 00′	35
25° 10′	40
30° 00′	45
35° 15′	50
42° 15′	55
51° 18′	60
64° 20′	65
82° 20′	70
111° 58′	75
170° 10′	80
342° 58′	85
0	90

To be able to construct other azimuths, a line is drawn that is parallel to the east-west line and crosses over the centre of the first azimuth. This can be done in the following way: The legs of a compass are opened as wide as the distance between the centre of the first azimuth and the apex. Its needle is then fixed at the east-west point, and the compass is rotated to the position farthest away from the instrument, meaning 90 degrees from the side of the instrument and wherever the pencil lead points is marked. A line between this mark and the centre of the first azimuth is drawn and extended as far as possible along the wooden piece. All centres of the azimuth are located on this line.

Once the wooden piece is placed and the full circle and the line are constructed, the first azimuth is used to prepare a new ratio scale for all azimuths. The radius of the first azimuth is divided into a 30-degree scale. Qunawī advises the maker to extend this scale along the wooden piece up to 342 degrees 58 minutes, which is the diameter of 85-degree azimuth. In order to avoid crowding the lines and arcs, traditionally the azimuths were constructed for each 5 or 10 degrees. Qunawī follows this tradition and provides a table of ratio values for every 5-degree azimuth (see Table 4). This table shows the distances between the centres of the azimuths and the centre of the first azimuth on the x-axis. There is no need to calculate any diameter, since the zenith and the location of the centre of the azimuth are known. This construction method is as follows: The needle is fixed at the located centre of the intended azimuth. The legs are opened until the pencil lead reaches the zenith. An arc is then constructed on the instrument's surface. The operation is repeated for every 5 degrees of azimuths, except for 90, because the 90-degree azimuth is on the meridian line and therefore infinite.

Conclusion

Qunawī ends his instructions with azimuth construction. But several arcs and scales on the standard constructed instrument were not described in the text, such as shadow scales, afternoon prayer scales, and seasonal hours. Although he knows about them, he does not explain why he did not include this information.

The astrolabe quadrant shown at the end of this article is constructed for the latitude of Edirne 42 degrees in accordance with the Qunawī's instructions and calculations. Therefore, it is missing some essential arcs and scales. When closely investigated, one can see that there are some visible mistakes due to Qunawī's approximate values for almucantars disregarding the half degrees. We preferred not to correct them so that we could give a clear picture of his calculations. That being said, we may never be certain whether these values are indeed his or those of his copyists', since we do not have the original manuscript. In any case, most of Qunawī's values are remarkable in that their margin of error is only 10 mm.

Hadiyyat al-mulūk, albeit not a perfect example and in fact one that is incomplete in its description, is still one of the rarest and without a doubt one of the most influential works on making the astrolabe quadrant in Ottoman astronomical literature. It is most likely the oldest treatise of its kind written in Turkish. Qunawī's simplification of the methods and topics, as well as his decision to avoid sharing the complex trigonometrical formulas so as not to confuse the makers, made this work popular and user-friendly.

His insistence upon writing in Turkish helped the Ottomans obtain and digest scientific knowledge rather easily. While most of his works reflect Mamluk influence, *Hadiyyat al-mulūk* also shows evidence of reflections from different sources from the Muslim world, such as Bīrūnī's. One can only hope that future studies will present more solid evidence of the relations among Bīrūnī, Mamluk astronomers, and Ottomans in terms of instrument making.

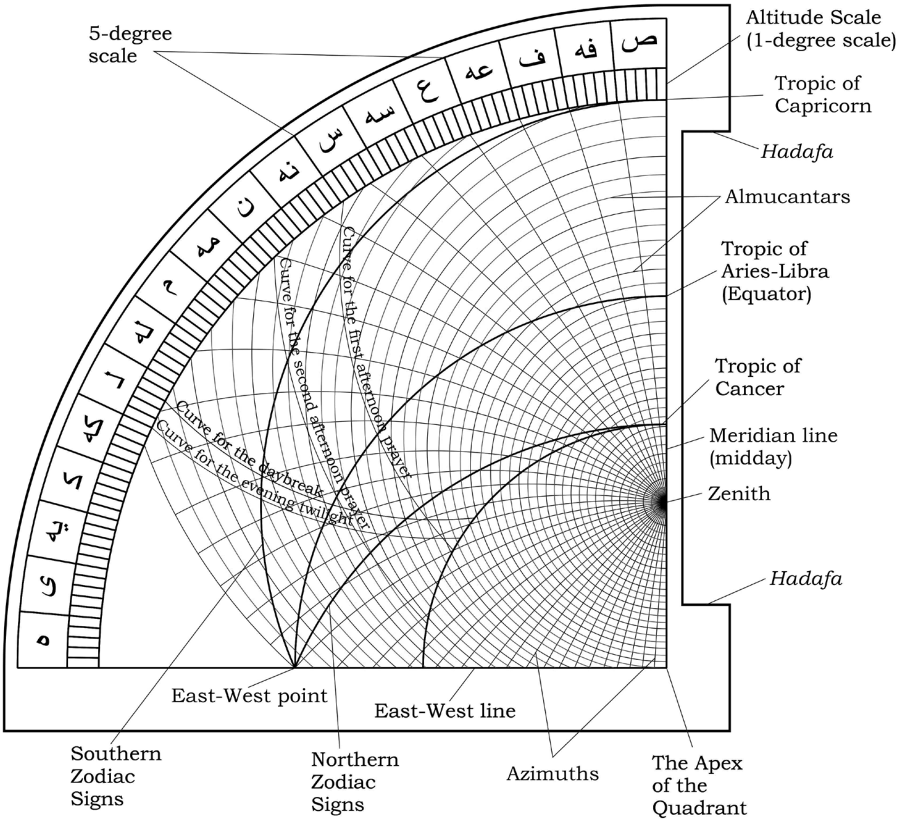

Figure 4. An example of an astrolabe quadrant constructed for 42-degree latitude according to Qunawī's instructions and his table of radiuses.

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