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al-Khwārizmī and Practical Astronomy in Ninth-Century Baghdad. The Earliest Extant Corpus of Texts in Arabic on the Astrolabe and Other Portable Instruments

François Charette

Dibner Institute, MIT
Cambridge, Mass.

Petra G. Schmidl

Institute for the History of Science
Frankfurt am Main

Unserem Doktorvater Abu Max gewidmet

Summary: This paper contains an edition with translation and commentary of a corpus of short tracts on portable instruments, preserved in two complementary manuscripts (Berlin Landberg 56 and Istanbul Aya Sofya 4830). Some of these texts are explicitly attributed to the ninth-century Abbasid scientist Abū Jaʿfar Muḥammad ibn Mūsā al-Khwārizmī. The lengthiest one is a treatise on the use of the astrolabe – the earliest such text in Arabic that is preserved – which until now has only been available in German and Russian translations. All other texts are here published for the first time. This 'Khwārizmiana' gives us a vivid evidence for al-Khwārizmī's innovative involvement with practical astronomy, which bears witness to the scientific interests of the cultural elite of Abbasid Baghdad during the first half of the ninth century.

I Introduction*

Muḥammad ibn Mūsā al-Khwārizmī, the extolled founder of algebra, is perhaps the most notably mythicised icon of Islamic science. In stating this, we do not intend any devaluation of his accomplishments, but we make the equally bold claim that the true nature of his scientific interests, goals and practices have never been

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appropriately understood within the context of early Abbasid culture.[1] This may have to do with the very limited biographical information available on him, and the semilegendary reports (in the primary and secondary literature) on the institution patronized by the caliph al-Maʾmūn, to which al-Khwārizmī is generally thought to have been one of the foremost associates, namely, the famous *Bayt al-Ḥikma* (House of Wisdom).[2] The frequent references in the secondary literature to al-Khwārizmī's pioneering 'genius' and 'revolutionary' achievements focus on the theoretical part of his *al-Kitāb al-Mukhtaṣar fī al-jabr wa-l-muqābala* and make complete abstraction of its *practical* parts as well as of all his other writings in the mathematical sciences – the almost entirety of which have been preserved, either in Arabic or in Latin translation.[3] The prevalence of al-Khwārizmī's concerns for the practical utility of scientific knowledge is, however, nowhere as obvious as in the very introduction of that treatise, in which he tells us that al-Maʾmūn's patronage has encouraged him

> to compose an abridged work on algebra (*al-jabr wa-l-muqābala*), in which I concentrate on the most subtle and noblest operations of reckoning needed by people for (the apportionement of) their successions and bequests, their shares (in commercial associations) and law-suits, for their commercial transactions and for all matters they might encounter relating to surveying, the digging of canals, geometry and other similar things.[4]

This paper is concerned with a corpus of early ninth-century texts on astronomical instrumentation and practical astronomy. Two of these are explicitly attributed to al-Khwārizmī and the remaining ones are anonymous, though most if not all of them clearly stem from the same milieu. A brief survey of most of this material has been already presented by David King,[5] in which he speculated whether some of the anonymous material might also be by al-Khwārizmī. In this paper we shall discuss the possible attribution of these texts to al-Khwārizmī in more detail. The texts presented here provide us with vivid evidence for the practical scientific preoccupations of the educated elite of early Abbasid Baghdad and Samarra, and they enrich our still too monochromatic picture of al-Khwārizmī's innovative involvement with a full spectrum of topics and problems pertaining to the mathematical sciences. It may also help to bring nuance and texture to our still relatively blurred understanding of scientific practice during the formative phase of Islamic science.

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[1]We thus strongly disagree with Gerald Toomer, according to whom "al-Khwārizmī's scientific achievements were at best mediocre" (*DSB*, VII: 362).

[2]See Gutas (1998: 53–60) for a convincing argument that this institution was in fact nothing more than an administrative palatial library that followed a common Sassanian model.

[3]A typical example of this triumphalist yet reductionist view can be found in Rashed (1997: 31).

[4]al-Khwārizmī (1968: 16).

[5]King (1983).

The core of this paper consists of an *editio princeps*, accompanied by a new translation and commentary, of al-Khwārizmī's treatise on the use of the astrolabe, the earliest extant work in Arabic pertaining to this ubiquitous genre of astronomical writing. Until now this text has been available in German and Russian translations[6] In addition to this central text, we also present editions of shorter tracts dealing with the construction of the astrolabe and the construction and use of other portable astronomical instruments such as the sine quadrant, the horary quadrant, the cylindrical dial, etc.[7] These texts are also edited for the first time and their translation appear for the first time in a Western language other than Russian.[8] Our edition is based on two complementary manuscript sources (which is to say that each text is preserved in only one of the two manuscripts), namely Berlin, Staatsbibliothek, Landberg 56, and Istanbul, Süleymaniye, Aya Sofya 4830.

I.1 Description of the Manuscripts

Berlin, Staatsbibliothek, Landberg 56

We shall denote this manuscript with the siglum $\mathcal{B}$. The first part of $\mathcal{B}$ (ff. 1–77r = Ahlwardt 5790) contains a fine copy of al-Farghānī's treatise on the astrolabe, entitled *al-Kāmil fī ṣanʿat al-asṭurlāb*.[9] The latter part (ff. 77v–97v = Ahlwardt 5793), contains the Khwārizmiana on which the present work is mainly based.[10] Since the most interesting codicological and paleographical features of this codex have never been discussed before, we thought it appropriate to present some relevant information here.

The title page (f. 2r) bears unintelligible inscriptions in the upper half and in the left margin. In the middle of the page, two lines of an inscription can be partially read, and the next two or three lines have been erased:[11]

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[6] Frank (1922) and Matvievskaya (1983), respectively. A few extracts were also edited by Prof. Paul Kunitzsch (1987), who has shown that they form in part the source of the *Sententiæ astrolabii*.

[7] We are not concerned with al-Khwārizmī's treatise on plane sundials, on which see p. 109 below.

[8] We provide below detailed references to published Russian translations.

[9] On this work see Sezgin (1969–84), VI: 150–151. A German translation of the introduction is in Wiedemann (1919). An edition and translation is currently being prepared by Dr Richard Lorch in Munich.

[10] This section of the Berlin manuscript has been previously discussed in relationship to al-Khwārizmī in Rozenfeld & Sergeeva (1977), King (1983a) and Bulgakov, Rozenfeld & Akhmedov (1983: 143–153).

[11] There are two or three illegible words on a fifth line, above which a later hand has inscribed in large letters the title and author of the treatise contained in the book: *Kitāb al-Kāmil li-l-shaykh Shihāb al-Dīn Aḥmad ibn Muḥammad ibn Kathīr al-Farghānī*.

السلطان [الأشرف] المعظّم ممهّد الدين اسماعيل بن عبّاس خلّد اللّه ملكه ...

This refers to the Yemeni Rasulid Sultan al-Malik al-Ashraf Ismāʿīl ibn ʿAbbās (reg. 778–803 H/1377–1400),[12] who was obviously alive when this note was written since it asks God to make the Sultan's dominion last forever. This provides us with a *terminus ante quem* for its dating. That of *ca.* 900 H. proposed by Ahlwardt is hence much too young. We would rather favour a dating of *ca.* 700–750 H. The title page also bears possession marks (with a seal from the Ottoman period) of one Muḥammad ibn Taqwā al-Ḥusaynī, who also owned the precious Ms. Paris ar. 2494 (apparently datable to the 6th c. H. — cf. Sezgin (1969–84), VI: 223) containing the unique copy of Abū 'l-Wafāʾ al-Būzajānī's famous astronomical handbook entitled *al-Majisṭī*.[13] A second possession notice in the lower left corner reads *fī ḥiyāzat al-faqīr Ṣāliḥ ibn Muḥammad al-Kawrānī* (?).

All folios save 1–7 and 10–15 are paginated in Arabic alphanumerical notation (*abjad*). This pagination is posterior to the copying of the manuscript but was made before the writing of the marginal notes on ff. 82r–83r (since on f. 82r the author of these glosses has deliberately avoided to write over the folio number). A modern European individual (probably its previous owner, the Swedish Arabist Carlo Landberg) has written the equivalent numbers in European 'Arabic' numerals beneath. The codex consists of thirteen quires generally of eight folios, labelled in words in the upper left corner of ff. 9r, 17r, 25r, ..., 97r, respectively. The total number of folios is noted in the upper left corner of f. 2r: *awrāq 97*.

The manuscript is the work of a single, careful copyist, whose handwriting, an excellent *naskhī*, shows characteristics which fit well with our suggested dating of *ca.* 700–750 H (See Figure 2 for a sample). The text is thoroughly vocalized and indicates most diacritical marks, as well as several additional marks that follow more ancient scribal conventions.[14] *Shadda*s, *sukūn*s and *hamza*s are also marked most of the time. The copyist has revised his text and noted occasional corrections in the margins. Glosses are otherwise rare. One reader (*ca.* 17th century) has written short glosses on ff. 3r and 32v, and he has corrected a word on f. 58r. The margins of ff. 82r–83r, on the other hand, are filled with extracts from an unidentified treatise on the use of the astrolabe (on account of the style, datable to the period *ca.* 1400–1600), of which we present an edition in Appendix 1 (cf. Figure 2 on p. 161). The

[12]This Sultan is well-famed as a litterateur for his history of the Yemen entitled *Fākihat al-zaman ... fī akhbār man malaka al-Yaman*, preserved in a probably unique manuscript in the John Rylands Library, Manchester: see Gottschalk *et al.* (1963), cols. 406–410.

[13]On this work see Carra de Vaux (1892).

[14]Undotted letters such as د are distinguished from their dotted counterparts (e.g., ذ) by a dot underneath: دِ (likewise with ص, ط *etc.*); the ʿ*ayn*s (ع) are distinguished from the *ghayn*s (غ) by a tailless ʿ*ayn* (ء) below.

entries of the tables on ff. 94r–95v combine the *abjad* and Indo-Arabic numerals, an unusual feature.[15] In our edition, we have reproduced them as they appear in the manuscript. Let us now describe the contents of $\mathcal{B}$:

1. 1–77r : al-Farghānī's astrolabe treatise entitled *al-Kāmil fī ṣanʿat al-asṭurlāb* (see note 9 above).
2. 77v–81v : An anonymous treatise on the construction of the astrolabe (*Ṣanʿat al-asṭurlāb*), with table on f. 78v and two sections entitled sqa *ʿAmal al-muqanṭarāt bi-'l-handasa* (79r–80v) and *ʿAmal al-ẓill fī ẓahr al-asṭurlāb bi-'l-handasa* (81r–81v). This section was believed by Wiedemann, Frank and others to be part of Farghānī's treatise.[16]) In our commentary we present some arguments for attributing it to al-Khwārizmī, as well as some evidence that runs contrary to this hypothesis. This is edited and translated here as Text 1.
3. 81v:4–91v:7 : al-Khwārizmī, On the use of the astrolabe (untitled, incipit: *Qāla Muḥammad ibn Mūsā al-Khwārizmī. Awwal mā yaḥtāj ilayhi al-nāẓir fī 'l-ʿamal bi-'l-asṭurlāb*[17]). This is edited and translated here as Text 2. As mentioned above, this text has previously been translated into German and Russian.[18] There is no title, and it is not completely clear where the treatise actually ends.[19] The chapters from the bottom of f. 88r to line 7 of f. 91v (corresponding to §24–§31 in our edition) have individual, centered headings in the manuscript.
   From f. 91v onwards there are various sections with individual headings, which save for one, are not related to the use of the astrolabe. We list here these additional sections as separate items.
4. 91v:8–92r:16 : On the construction and use of a compass for finding the times of prayer (*ʿAmal birkār yuʿraf bihi al-awqāt li-'l-ṣalāt wa-yuqās bihi al-ẓill* and *Ṣifat al-ʿamal bi-hādhā al-bīkār* [sic]). This text was translated in German by J. Frank and E. Wiedemann (1919). It is edited and translated here as Text 3.
5. 92r:17–93r : On the construction of a plate for measuring the altitude and finding the times of moonrise and moonset (*ʿAmal ṣafīḥa yu'khadh bihā al-irtifāʿ wa-yuʿraf bihā ṭulūʿ al-qamar fī kull laylat wa-matā yaghīb wa-kam yamkuth.*). On f. 93r there is a diagram of the instrument. This text has never been previously translated. It is edited and translated here as Text 4.
6. 93v : Table of the normed right ascension for each 3° of solar longitude ($3° \leq \lambda \leq 90°$), given with two sexagesimal fractions. Numerical investigation

[15]For an example see Figure 4 on p. 162. Cf. King (1983a: 11 and Plates 2 and 3.).

[16]See Frank (1922: 5).

[17]The manuscript has erroneously *fī ʿamal al-asṭurlāb*.

[18]See note 6.

[19]Frank (1922: 5) and Kunitzsch (1987: 234, n. 5) have already made this observation.

suggests an underlying obliquity of 23°35′,[20] but some evidence also suggests a link to al-Khwārizmī.[21] This table is edited in Appendix 2.

7. 94r : Table of the solar altitude at the times of the day prayers (*ẓuhr*, beginning of *ʿaṣr* and end of *ʿaṣr*), for each 6° of solar longitude and for latitude 33°.[22] This table actually belongs to item 3 and has been misplaced in the codex. It was thus overlooked in the study by Frank and Wiedemann (1919); Its relationship with the treatise on the compass was first established by King (1983a: 7), and it has been recently investigated in King (2004, I: 233–235, 568–569). We have integrated this table to our edition of Text 3.
8. 94v : Table of the solar altitude at each temporal hour as a function of the meridian altitude h_m (with $25° \leq h_m \leq 90°$). This is edited in Appendix 2.
9. 95r-v : Table of the 'sine of the hours', a curious name denoting an auxiliary function for computing the previous table. Jan Hogendijk has established that this table stems from al-Khwārizmī.[23] This is edited in Appendix 2.
10. 96r : A 'chapter' on the different 'species' of astrolabes (*bāb maʿrifat al-ʿilla allati summiya bihā al-aṣṭurlāb tāmman wa-summiya nisfan wa-thulthan wa-sudsan wa-ghayr dhālika min al-asmāʾ*). Frank (1922: 16) included this item and the next two in his translation of item 2, but it is doubtful whether they really belong to it. This is edited and translated here as Text 5.
11. 96r-v : Finding the projection of the rays with the astrolabe (*maṭraḥ al-shuʿāʿ bi-'l-aṣṭurlāb*). Translation in Frank (1922: 17). This is edited and translated here as Text 6.
12. 96v : Ptolemy's definition of the five terrestrial zones (*qismat Baṭlamiyūs: al-ṭarāʾiq al-khamsa*). Translation in Frank (1922: 17). This is edited and translated here as Text 7.
13. 96v–97v : On the construction and use of the sine quadrant (*ʿamal rubʿ yustakhraj minhu al-jayb ilkh* and *ṣifat al-ʿamal bi-hādhā al-rubʿ idhā ʿumila*). This text has never been previously translated. It is edited and translated here as Text 8.
14. 97v : A table without title, in a much later handwriting, giving for each temporal hour and each zodiacal sign the solar altitude. The signs are incorrectly arranged and one column is missing. The entries are extremely corrupt, but seem to imply an underlying latitude of 32°9′ and an obliquity of 23°34′. We have not included it in our edition since it obviously does not belong to the

[20] On this value see p. 163.

[21] King (2004, I: 147, n. 11) has shown that two of the three values of the right ascension given in a Latin text relating to al-Khwārizmī's table of a certain auxiliary function can be explained from our right ascension table.

[22] The manuscript has 13°, a trivial scribal error.

[23] See Hogendijk (1991). Cf. King (2004, I: 89, 92).

Abbasid corpus that is the subject of this paper.[24]

Istanbul, Süleymaniye, Aya Sofya 4830

This valuable manuscript (which we shall denote with the siglum $\mathcal{A}$), copied in Damascus in Ramaḍān 626 H [= July-August 1229 AD],[25] is a bulky *majmūʿa* of 235 folios which contains several important Greek, Abbasid and Buyid mathematical and astronomical works, by authors such as Apollonius, 'Aqāṭun', al-Kindī, Thābit ibn Qurra, Abū Sahl al-Kūhī and Ibn al-Sarī. It also contains numerous – mostly anonymous – short tracts on astronomical instruments, spherical astronomy, gnomonics and mathematical geography. This manuscript was briefly described in Ahmedov, ad-Dabbagh and Rosenfeld (1987) with special condideration for the material contained on ff. 183r–199v and 228v–235r, wherein two texts are explicitly attributed to al-Khwārizmī. They thereby naïvely assumed that every single item within this group could be attributed to al-Khwārizmī:

> [T]he fact that all the group of treatises that are in f. 182a[*sic*]–199b and f. 228b–235a of this codex belongs to Al-Khwârizmî was established by D. A. King … on the basis of closeness of the language and the topics studied in these treatises, to which it should be added such a distinctive feature for the time of Al-Khwârizmî as the value of 'the complete sine' … equal to 150 which was borrowed from Brahmagupta.[26]

In fact, King stated that "the problem of the attribution of each one of them [i.e., the seven texts investigated in King (1983a)] to al-Khwārizmī – a problem which I am the first to admit exists – may not be solved until the discovery of new material".[27]

In their paper, Ahmedov, ad-Dabbagh and Rosenfeld organized the above material – quite unfittingly – into 59 'chapters', thus conferring illusory unity to an hodgepodge of texts. This confusion is repeated in Rosenfeld and İhsanoğlu (2003: 24–25). In this paper we shall restrict our attention to the following three texts, of which we provide an edition and translation with commentary:

1. A passage on finding the azimuth and determining the meridian with the astrolabe (ff. 198v–199r), explicitly attributed to al-Khwārizmī (but different from the equivalent section in $\mathcal{B}$:89v–90r). This has been translated into Russian in Rosenfeld *et al.* (1983: 216–217) together with the unrelated material immedi-

[24]See however King (1983: 29, and 27 Plate 8 and Table 9).

[25]On this codex see Rosenthal (1956), Rashed (1993–2002, vol. 1: 841, vol. 3: 498, vol. 4: 601–602), and Ahmedov, ad-Dabbâgh & Rosenfeld (1987).

[26]Ahmedov, ad-Dabbâgh & Rosenfeld (1987: 164).

[27]King (1983a: 2).

ately following it in the Istanbul manuscript on ff. 199r–199v (*Ibid.*: 217–219). It is edited and translated here as Text 9.

2. An anonymous treatise on the horary quadrant (ff. 196v–197r) which may be attributable to al-Khwārizmī or his milieu. Russian translation in Ahmedov (1991: 193–195). It is edited and translated here as Text 10.
3. An anonymous tract on a portable sundial called the *mukḥula* (f. 192r, with illustration on f. 192v), probably *not* by al-Khwārizmī, but nevertheless clearly from the ninth century. Russian translation in Ahmedov (1991: 187–189). It is edited and translated here as Text 11.

But before turning to the specific topic of our paper, we think it is worth mentioning other anonymous tracts in the Aya Sofya manuscript which obviously relate to the general concern of this paper for the practical scientific interests in Abbasid society.

- 189r–190r : On a water-clock (*binkān*).[28]
- 190r–190v : On a water-clock that shoots pebbles.[29]
- 191r–192r : On a horary lifting wheel (*dawlāb*)[30]
- f. 193r : On a double sundial on the slopes of a roof, called *maknasa*.[31]
- 194v–196v : A geographical table indicating the latitudes and longitudes of 163 localities.[32]
- 197r–197v : On an 'optical compass' to trace large circles, e.g. around a military camp, hence called *birkār al-ḥilla*.[33]
- 198r : On an instrument for predicting lunar eclipses, being the work of ʿUmayr ibn Samʿān (unidentified) (*lawḥ fī maʿrifat al-kusūf, ʿamal ʿUmayr ibn Samʿān*) with a diagram on 198v labelled *Āla yuʿlam bihā al-kusūf*.[34] This text should be investigated in a separate study – yet to be conducted – devoted to the early history of instruments for predicting eclipses (sometimes called *eclipsiorum* in medieval Latin).[35]
- 199r–199v : On the latitudes of the seven climates (*Maʿrifat ʿurūḍ al-aqālīm*)

[28] Russian translation in Ahmedov (1991: 182–185).

[29] Translation in Ahmedov (1991: 185).

[30] Translation in Ahmedov (1991: 185–187).

[31] See Charette (2003: 205–207). Not in Ahmedov (1991).

[32] Not in Ahmedov (1991).

[33] Text and English translation in Ahmedov, ad-Dabbâgh & Rosenfeld (1987: 182–184); Russian translation in Ahmedov (1991: 197–198).

[34] Translation in Ahmedov (1991: 199–200).

[35] On an eclipse plate by al-Kāshī see Kennedy (1951). On medieval Latin examples see North (1976, II: 265–270, III: 211–216).

with table.[36]

- 200r : Diagram of an instrument with circles for the earth, moon and sun, probably related to the eclipse plate described on ff. 198r–198v.
- 231v–235r : al-Khwārizmī, Treatise on plane horizontal sundials (*ʿAmal al-sāʿāt fī basīṭ al-rukhāma*).[37] David A. King has recently questioned al-Khwārizmī's authorship of this treatise,[38] but we have argued elsewhere that there is in fact no reason to doubt it.[39]

Remarks on the edition and translation

We have divided the material edited in this paper into eleven different items, to which we shall refer as 'Text 1', 'Text 2', etc. Some of the material in Text 2 has been slightly reordered to preserve thematic consistency. In the edition we indicate restorations of words or passages that are missing in the manuscript by putting it between acute brackets $< \cdots >$. Restorations of completely illegible words – mostly because of wormholes – are enclosed by square brackets [...], whereas passages that have to be removed in order to render the text intelligible are indicated by curly brackets { ... }.

[36] Russian translation in al-Khwārizmī (1983a: 217–219).

[37] Partial Russian translation in al-Khwārizmī (1983b: 221–232). Cf. King (1983a: 17–20).

[38] King (1999: 349–350).

[39] Charette (2003: 181); see also Charette & Schmidl (2001: 110–111).

II Edition

Text 1: On the construction of the astrolabe — $\mathcal{B}$:77v–81v

بســـم الله الرحمن الرحيـــم

صنعة الأصطرلاب

معرفة أنصاف الأقطار من الجدول المُثبَت فيه بُعد ما بين[1] المركز والمقنطرات التي تقع في الشمال والجنوب عن معدّل النهار على خطّ نصف النهار لدرجةٍ درجة

إذا أردت ذلك فاقسم <نصف> القطر ١٥٠ ثم انقص العرض الذي تريد العمل له من ٩٠ فما بقي تأخذ ما بحذائه في السطر الأول وهو الشمالي[2] وهو بعد أفق هذا العرض من مركز الأصطرلاب ثم تزيد[3] عليه ما في السطر الثاني وهو الجنوبي ثم تأخذ نصف ما اجتمع فهو نصف قطر أفق العرض الذي أردته

فإن أردت نصف قطر مقنطرة أخرى[4] من اللّواتي بين المركز والأفق فإنّك تنقص من العرض بعدد المقنطرة التي أردت فما يبقى تنقصه من تسعين وتأخذ ممّا بحذائه في السطر الأول فهو بعد تلك المقنطرة من مركز الأصطرلاب إلى ناحية الأفق فتحفظه ثم تزيد على العرض عدد[5] هذه المقنطرة فما بلغ نقصتَه من ٩٠ وتأخذ ما بحذائه في السطر الثاني وتزيده على ما حفظت وتأخذ نصفه فهو نصف قطر المقنطرة التي أردت

فإن كانت المقنطرة من اللّواتي بين المركز وناحية ⟨78r⟩ العلاقة فإنّك تنقص العرض من المقنطرة فما بقي نقصته من ٩٠ فما بقي أخذت ما بحذائه في السطر الأول <واحفظه> ثم تزيد العرض على عدد المقنطرة فما اجتمع نقصته من ٩٠ فما بقي تأخذ ما بحذائه في السطر الثاني فتنقص منه الذي حفظته فما بقي أخذت نصفه فهو نصف قطر تلك المقنطرة ولا تزال تفعل ذلك إلى أن يخرج لك ما بحذاء المقنطرة التي تريد أقل من ١٥٠ فعند ذلك تدخل الدائرة في الصفيحة وتستغني عن أنصاف الأقطار

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[1] بَعد ما نُبيّن MS [2] الشمال MS [3] تدير MS [4] أُخرا MS [5] نُعد MS

⟨78r⟩ **جدول** استخراج مقنطرات جميع العروض فيه المراكز والأنصاف
ما بين مركز الأصطرلاب وبين مواضع المقنطرات في خطّ نصف النهار إلى الشمال والجنوب
عن معدّل النهار جيّد ممتحن على أحسن ما يكون إن شاء اللّه تعالى والقوة باللّه

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عدد	شمال	جنوب	عدد	شمال	جنوب	عدد	شمال	جنوب
ا	صو لا	صط يد	لا	نه لد	قعجلح	سا	كه كد	شعط لط
ب	صد يا	قا م	لب	ند كز	قعز ح	سب	كد كط	شصجمط
ج	صجيب	قجكح	لج	نج يط	قف ن	سج	كج لد	تط[d] ٠
د	صا له	قه[a] يح	لد	نب يج	قفد م	سد	كب م	تكه نح
ه	فط نط	قز ط	له	نا ز	قفح لز	سه	كا مو	تمب ند
و	فح كه	قط ب	لو	ن ب	قصب مب	سو	ك نب	تسا يز
ز	فو نج	قي يح	لز	مح نز	قصو يو	سز	يط نح	تفب[e] لو
ح	فه كب	قيب يز	لح	مز نج	را يط	سح	يط ه	ثه ح
ط	فج نب	قيد يح	لط	مو ن	ره يب	سط	يح يب	ثكط مو
ي	فب كج	قيز ا	م	مه مو	ري له	ع	يز يط	ثنو نب
يا	ف نو	قيط ز	ما	مد مه	ريه كح	عا	يو كو	ثفو مه
يب	عط لا	قكا يه	مب	مج مج	رك لب	عب	يه لج	خيط نز
يج	عح ح	قكجكو	مج	مب مب	ركه مط	عج	يد م	خنز ٠
يد	عو مه	قكه م	مد	ما ما	رلا يط	عد	يجمح	خصح لط
يه	عه كج	قكز نز	مه	م ما	رلز ه	عه	يب نه	ذمه مد
يو	عد ب	قل يز	مو	لط ما	رمج[b] ب	عو	يب ج	ذص[ط م]ب
يز	عب كط	قلب ما	مز	لح مب	رمط يو	عز	يا يا	ضس[ا[f] ي]ط
يح	عا ما	قله ح	مح	لز مب	رنه مز	عح	ي يط	ظلد يا
يط	ع ب	قلز له	مط	لو مج	رسب لو	عط	ط كز	غيط مج
ك	سح مه	قم يج	ن	له مد	رسط مه	ف	ح له	غقكب مح
كا	سز كط	قمب يد	نا	لد مو	رعز يد	فا	ز مج	١٢٤٧ لو
كب	سو يد	قمه لد	نب	لجمح	رفه ه	فب	و نا	١٤٠٤ ط
كج	سه مط	قمح كا	نج	لب نا	رصجكا	فج	و ٠	١٦٠٥ كا
كد	سجمه	قنا يب	ند	لا نز	شب ه	فد	ه ح	١٨٧٣ ل
كه	سبلج	قند ح	نه	ل نز	شيا ك	فه	د يز	٢٢٤٨ يا
كو	سا كا	قنز م	نو	ل ا	شكا ح	فو	جكو	٢٨١١ يب
كز	س ي	قس يج	نز	كط ه	شلا ل	فز	ب لد	٣٧٤٨ ز
كح	نط ٠	قسجكد	نح	كح ط	شمبكح	فح	ا مج	٥٦٢٤ يا
كط	نز يا	قسو ما	نط	كز يد	شند يا	فط	٠ نب[c]	١١٢٥٢ ن
ل	نو مب	قع د	س	كو نط	شسوك	ص	٠ ٠	٠ ٠

[a] قد MS [b] رمح MS [c] ىب MS [d] ك corrected to ط MS [e] تعب MS [f] ... ضمسـ MS

الكواكب ⟨78r⟩ فإذا أردت أن تعرف بعد كلّ كوكب من الكواكب الثابتة من المركز من الأقسام التي قسمتَها[6] لمائة وخمسين ممّا بين مركز الأصطرلاب ورأس الجدي من هذا الجدول إن شاء اللّه تعالى وبه القوة

⟨79r⟩ إذا أردت ذلك فانظر كم بُعد الكوكب من معدّل النهار وشمالي هو أم جنوبي فما أصبتَ بعده من معدّل النهار فادخله في سطور العدد وخذ ما بحذائها[7] في السطور الأول إن كان بعد الكوكب شمالي من معدّل النهار فما كان فهو بعد الكوكب من المركز وإن كان معك دقائق فعدّلها وإن كان بعد الكوكب جنوبي فخذ ما بحيال العدد من السطور الجنوب فما كان فهو بعده من المركز وإن كان معه دقائق فعدّلها حتى تصحّ إن شاء اللّه تعالى

عمل المقنطرات بالهندسة

أدر دائرةً مثل سعة صفيحتك ثم اقسم نصف قطرها نه جزءًا هو[8] خطّ[9] اب ثم استخرج من نقطة المركز عمودًا طوله كد جزءًا من هذه نه الجزء وعلى زاوية قائمة من المركز وهو خطّ[10] بج ثم خطّ من نقطة ج خطًّا إلى نقطة ا وهو جا ثم تأخذ خطّ جا فتضعه ناحيةً ثم تُصيّره نصف قطر وتُدير عليه دائرةً يكون جا نصف قطرها وهذه الدائرة تأخذ منها مراكز المقنطرات ثم ربّع هذه الدائرة ثم خذ خطّ بج الذي هو كد[11] جزءًا فضعه من نقطة ج المركز تبلغ نقطة د ثم استخرج من نقطة د خطًّا يوازي قطر ⟨79v⟩ اج واخرجه في جهة ألف إلى غير نهاية وهو خطّ زح ويقطع الدائرة عند ز فيكون حينئذٍ خطّ زد بقدر خطّ اب من الدائرة الأولى ثم اكتب على قطر جد على طرفه ط ك ثم اقسم ربع اط بتسعين

ثم استخرج عرض الصفيحة ثم عدّ من نقطة ط بقدر عرض الصفيحة التي تريد أن تعمله فكأنّه نقطة ي ثم ضع مثل هذا القدر من عند نقطة ك إلى ح وهو ك ل[12] ثم مدّ من نقطة ط خطًّا يمرّ على نقطة ي عرض البلد حتى يقع على خطّ زح خارجًا من الدائرة فوقع على نقطة ش[13] ثم مدّ أيضًا من نقطة ط خطًّا إلى ل ثم انظر أين قطع من خطّ رح فكأنّه موضع م فمن نقطة د إلى نقطة م بعد وسط الأفق من خطّ المشرق والمغرب ونصف خطّ ش م مركز الأفق[14]

فإذا أردت[15] وضعت رجل البيكار كان بهذا الفتح وهو خطّ ش ن ثم وضعته[16] على [أين] خطّ وسط السماء وافق[17] [خطّ] رأس الحمل والميزان والنقطة التي خرجت لك التي بعدها من خطّ المشرق والمغرب بقدر دم ثم أدر حينئذفاٍ فقد استخرجتَ الأفق وكذلك العمل في[18]

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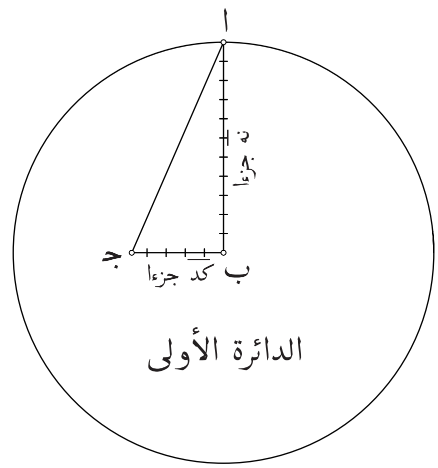
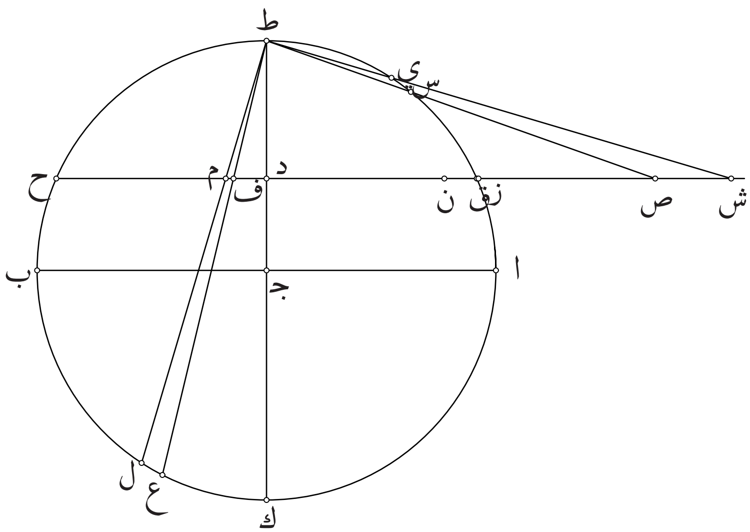
[6] Only ق ... تها is legible on the MS [7] بحداها MS [8] Wormhole [9] خُط MS [10] خُط MS [11] كد MS [12] ك ل] كل MS [13] س MS [14] من خطّ المشرق ... مركز الأفق] marg. MS [15] Wormhole
[16] Partly illegible (wormhole). [17] وافا MS [18] العمل في] Marg. MS [19] أو ٣] ا و ٣ MS

الأفق لكلّ عرض كذلك ثم زد على عرض البلد ستّة إن كان الأصطرلاب سُدسًا أو ٣[19] إن كان ثُلثًا فكأنّك زدتَ على نقطة < ي > ستّة <أجزاء> فصارت قوس ط س ثم مدّ خطًّا من ط يمرّ على س إلى خطّ زح ⟨80r⟩ فكأنّه وقع على ص ثم ارجع إلى خطّ ك ل فانقص منه ستّة أجزاء ممّا يلي ل فيكون ع <فمدّ> خطًّا <من ط إلى ع> فكأنّه قطع من خطّ زح موضع ف فخطّ دف بعد المقنطرة الثانية من خطّ المشرق والمغرب ونصف خطّ ص ف نقطة ق فخطّ ص ق بعد مركز المقنطرة الثانية إذا وضعته على خطّ وسط السماء وكذلك لجميع المقنطرات إن شاء الله عزّ وجلّ



80r



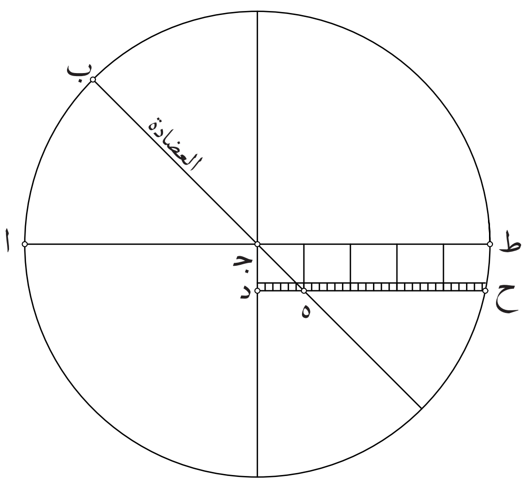
80v

يقسم ربع اط بتسعين ومنه يؤخذ الحساب

⟨81r⟩ **عمل الظلّ في ظهر الأصطرلاب بالهندسة**

تأخذ من المركز وهو نقطة جـ بالبيكار بقدر ما يحسُن وهو ستّة أجزاء من ص[20] فكأنّه جـ د ثم تخرج خطّ دح موازي لخطّ[21] ط ا الذي هو خطّ المشرق والمغرب ثم تقسم خط جـ د باثنى عشر وتقسم خطّ دح بتلك الأقسام { ما خُرِج من شيء } ثم تخطّ خطًّا آخر موازيًا لخطّ[22] ط جـ ويكون إلى ح د أقرب بقدر ما يحسن ثم قطع الأجزاء خمسات كما ترى[23] في الصورة في الخطّ الذي يلي خطّ ح د واكتب عليها بالجُمَّل في الخطّ الذي[24] يلي ط جـ كما ترى وابدأ بكتابة[25] و ممّا يلي مركز الصفيحة فإنّك إذا أخذت الارتفاع بالعضادة خرج لك الظلّ من أجزاء القائم الذي هو اثنا عشر الذي هو جـ د

مثال ذلك إذا كان الارتفاع قوس اب وكان خطّ دح موازي لخطّ الأفق الذي هو خطّ ط ا وكان المقياس القائم خطّ جـ د[26] كان ظلّ خطّ جـ د د ه فإذا كان الارتفاع الذي[27] هو قوس اب نصف ص وهو مه كان ده مثل جـ د فإذا قسمتَ جـ د الذي[28] هو المقياس يب وقسمت دح بتلك الأقسام خرج لك بتلك الأجزاء فيخرج لك ظلّ ساعة نيّف وستّين جزءًا كلّ ⟨81v⟩ اثنى عشر منها مثل خطّ جـ د الذي[29] هو المقياس فافهم ذلك ولا قوّة إلّا بالله وهذه صورة ذلك وكلّ[30] واحد من هذه الأجزاء جزئين لأنّ طول كلّ قسم مثل خطّ جد فكلّ بيت اثنا عشر



[20] See the commentary. [21] لخطّ] خط MS [22] خط MS [23] ترا MS [24] والّذىْ MS [25] بكتاب MS
[26] جد MS [27] الذي] والّذىْ MS [28] الذي] والّذىْ MS [29] والّذىْ MS [30] وكلّ] كل MS

Text 2: On the use of the astrolabe — $\mathcal{B}$:81v–91v

[1] ⟨81v⟩ **قال محمد بن موسى**[1] **الخوارزمي** أول ما يحتاج إليه الناظر في العمل بالأصطرلاب[2] **أخذ الارتفاع** فإذا أردت أخذ الارتفاع فاقلب الأصطرلاب بظهرها (!)[3] ثم علّقها بيمينك وحاذ[4] ⟨82r⟩ الشمس بمنكبك الأيسر واجعل الخطوط التسعين التي[5] في ظهر الأصطرلاب نحو عين الشمس ثم لا تزال ترفع العضادة حتى ترى الشمس قد دخلت من ثقبيها جميعًا ثم انظر أين وقع المري الذي في العضادة وهو طرفها المحدّد من الأجزاء[6] التسعين التي في ظهرها فما كان فهو ارتفاع الشمس في تلك الساعة فاحفظه

[2a] **إذا أردت أن تعرف الطالع وما مضى من النهار من ساعةٍ وكسر ساعة** فخذ الارتفاع على ما وصفتُ لك ومثل ذلك ما قد عرفتَ <من> موضع الشمس في برجها ودرجتها ثم ضع درجة الشمس من برجها على مثل ذلك الارتفاع من المقنطرات من ناحية المشرق إن كان قياسك قبل نصف النهار وإن كان قياسك بعد نصف النهار فمن ناحية المغرب ثم انظر أول المقنطرات من ناحية المشرق أيّ برج قطعت وكم درجةً[7] منه فبعدد تلك الدرج من ذلك البرج هو الطالع ثم انظر نظير درجة الشمس على كم ساعة وقع وابدأ بعدد الساعات من ناحية المغرب فما كان فهو ما مضى من النهار من ساعة وكسر ساعة إن كان كسر فاحفظ الساعات الصحاح

[2b] فإن أردت أن تعرف الكسر ⟨82v⟩ وهو ما زاد على الساعات الصحاح فانظر مري الأجزاء الذي هو رأس الجدي أين وقع من الدرج التي هي[8] على الحجرة ثم انظر نظير درجة الشمس حتى تضعها على الساعة التي تمّت ثم انظر كم زال مري[9] الأجزاء عن موضعه الذي كان به فما كان من الدرج فهو ما زاد على الساعات الصحاح وهو منسوب إلى أجزاء ساعات النهار في ذلك اليوم

[2c] **فإذا أردت أن تعرف أجزاء ساعات النهار** فردّ نظير درجة الشمس إلى ساعة أخرى من موضعها هذا الثاني ثم انظر كم زال مري الأجزاء عن موضعه الثاني فما كان فهو أجزاء الساعات فاحفظه وانسب إليه ذلك الكسر فما كان فهو ما مضى من النهار من ساعة وأجزاء ساعة ثم انظر خطّ وسط السماء الذي بحذاء العلاقة أي برج قطع وأي درجة فهو درجة وسط السماء ووتد الأرض مثل ذلك

[2d] **مثال ذلك** إنّا قسنا الشمس بمدينة السلٰم فوجدنا الارتفاع أربع وعشرين درجةً في أول النهار وكانت الشمس في $\overline{\text{١٢}}$[10] درجةً من العقرب فوضعنا درجة الشمس على أربعة

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[1] مُوسًى MS [2] العمل بالأصطرلاب] عمل الأصطرلاب MS [3] Note the consequent usage of اصطرلاب as a feminine (perhaps as an ellipsis for *ālat al-aṣṭurlāb*). [4] حاذي MS [5] الذي MS [6] أجزا MS [7] درجةٍ MS [8] هو MS [9] موري MS [10] ١٤ MS

وعشرين من المقنطرات من ناحية المشرق لإنّ الارتفاع كان أول النهار فوجدنا مقنطرة المشرق قطعت ⟨83r⟩ من البروج[11] تسع درج من القوس فعلمنا أنّ الطالع تسع درج من القوس ووجدنا وسط السماء ٢٢ درجةً من السنبلة وكان نظير درجة الشمس ١٢[12] من الثور ووجدنا قد وقع على بعض الساعة الثالثة فنظرنا إلى مري[13] الأجزاء فوجدناه على مائتين وثلاث وستّين درجة التي على حجرة الأصطرلاب فحفظناه

ثم رددنا[14] نظير درجة الشمس فوضعناه على ساعتين تامتين فوجدنا مري الأجزاء قد زال عن موضعه ستّ درج فعلمنا أنّ الست الدرج زيادة على الساعتين وهو منسوب إلى أجزاء ساعات النهار ووجدنا مري الأجزاء قد صار على ٢٥٧ من الحجرة فحفظناه ثم أردنا أن[15] نعلم أجزاء ساعات النهار فرددنا نظير درجة الشمس إلى ثلاث ساعات تامات ثم نظرنا إلى مري[16] الأجزاء فوجدناه وقع على ٢٧٠ فأخذنا فضل بينه وبين ٢٥٧ فوجدناه ١٣ درجةً فعلمنا أن قد مضى[17] من النهار ساعتان وستّة أجزاء من ١٣ جزءًا من ساعة

[3] **وإن أردت أن تعرف الطالع والساعات باللّيل والقياس بالكواكب الثابتة** فعلّق الأصطرلاب بيمينك واستقبل بثقبي العضادة الكوكب الذي تريد القياس به ثم انظر من ثقبي العضادة حتى ترى[18] الكوكب ⟨83v⟩ بإحدى عينيك من الثقبين جميعًا ثم انظر إلى مري الأجزاء <وهو> مري[19] العضادة أين وقع من الخطوط فذلك ارتفاع الكوكب الذي قستَه ثم اقلب الأصطرلاب وضع رأس الكوكب المُحدَّد على مثل ذلك الارتفاع من المشرق إن كان الكوكب لم يزل عن وسط السماء فعلى مثل ذلك الارتفاع من ناحية المغرب <إن كان الكوكب قد زال عن وسط السماء> ثم انظر مقنطرة المشرق أي برج قطعت وأي درجة فهو الطالع وما قطع خطّ وسط السماء فهو درجة وسط السماء ثم انظر درجة الشمس أين وقعت من الساعات فهو ما مضى من اللّيل من ساعة واعمل بكسور الساعات بدرجة الشمس باللّيل كما تعمل[20] بنظير درجة الشمس بالنهار

[4a] **وإن أردت أن تعرف صحّة الأصطرلاب من خطائه** فقس الشمس واعرف الطالع وما مضى من النهار من ساعة على ما وصفنا في صدر الكتاب فإذا عرفت ذلك بالأصطرلاب فاعرفه بحساب الزيج فإذا وافق ما خرج لك بالأصطرلاب فالأصطرلاب صحيحة

[4b] **ومثـــــال ذلك** إنّا قسنا الشمس وهي في خمس عشرة درجةً من الثور فوجدنا الارتفاع ٤٤ درجةً فعرفنا ما مضى من النهار من ساعة بحساب الزيج فكان ثلاث ساعات وسُدس والذي[21] دار من الفلك ثلاثة وخمسين درجةً وخمس عشرة دقيقةً ⟨84r⟩ [...][22]

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[11] البرج MS [12] درجةً ... ١٢] marg. MS [13] موري MS [14] زدنا MS [15] أنّ MS [16] موزي MS
[17] فعلمنا أن قد مضى] فعلنا مضى MS [18] ترا MS [19] مُورَى MS [20] نعمل MS [21] والَّذىْ MS [22] Lacuna.

فأدخلناه في مطالع مدينة السلام الموضوع في الزيج فوجدنا ما بحياله من درج السواء كد درجة ودقيقتين من الحوت وهو درجة وسط السماء فإن خرج لك في الأصطرلاب مثل ذلك فالأصطرلاب صحيحة

[5a] **إذا أردت أن تعرف قوس النهار في كلّ يوم** فضع درجة الشمس على مقنطرة المشرق ثم انظر مري[23] الأجزاء أين وقع فتُعلِّم عليه ثم أدر درجة الشمس حتى تضعها على مقنطرة المغرب ثم انظر مري[24] الأجزاء أين وقع ثم عدّ ما بين موضع مري[25] الأجزاء الأول والثاني من العدد الذي على الحجرة فما كان فهو قوس النهار

[5b] **فإن أردت أن تعرف مقدار قوس اللّيل** فانقص قوس النهار من ٣٦٠ درجة فما بلغ فهو قوس اللّيل **فإن أردت قوس اللّيل بالأصطرلاب** فاعمل بنظير درجة الشمس

[5c] **وإن أردت ساعات النهار** فاقسم قوس النهار على ١٥ فما كان فهو ساعات ذلك اليوم فانقص ساعات النهار من ٢٤ فما بقي فهو ساعات اللّيل

[6] **وإن أردت أن تعرف مطالع الفلك المستقيم بالأصطرلاب** فضع أول خطٍّ من الجدي ⟨84v⟩ على خطّ وسط السماء ثم انظر كم قطع من الأجزاء المري[26] من حول الحجرة فهو ما يطلع به وكذلك سائر البروج

[7] **وإذا أردت أن تعرف مطالع كلّ بلد** فضع عرض البلد فوق الصفائح ثم اعترض أيّ برج شئت فضع رأسه على مقنطرة المشرق ثم أدره حتى ينتهي آخره وانظر مري[27] الأجزاء كم قطع فهو ما يطلع به وكذلك سائر البروج

[8] **وإذا أردت أن تعرف درجة الشمس** فخذ ارتفاعها في ذلك اليوم أرفع ما يكون ثم اعرف في أيّ ربع أنت من أرباع السنة فأدر بروج الربع الذي أنت فيه على خطّ وسط السماء فما وافق منها مثل الارتفاع الذي خرج لك فالشمس في تلك الدرجة

[9a] **إذا أردت أن تعرف درجة القمر والكواكب الخمسة** فخذ ارتفاع القمر وأيّ الكواكب شئت من الخمسة أرفع ما يكون ثم خذ ارتفاع كوكب من الكواكب الثابتة مع أخذك ارتفاع القمر وأيّ كوكب شئت من الخمسة فاعرف بالكوكب الثابت الطالع كما وصفتُ لك في صدر الكتاب ثم انظر خطّ وسط السماء في أيّ برج وأيّ درجة فالكوكب في تلك الدرجة

[9b] **إذا أردت أن تعرف عرض الكوكب** فانظر كم كان ارتفاع الكوكب الذي قستَ وعرفتَ موضعه فإن كان[28] أكثر من ارتفاع درجته ⟨85r⟩ التي وجدته فيها فخذ فضل ما بينهما فما كان فهو عرضه في الشمال وإن كان ارتفاع الكوكب أقلّ من ارتفاع درجته ففضل ما بينهما

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[23] MS مُوْرِي [24] MS مُوْرِي [25] MS مُوْرِي [26] MS المُوْري [27] MS موري [28] فإن كان] Marg. MS

عرضه في الجنوب

[10] **إذا أردت أن تعرف ميل أيّ درجة أحببتَ** فضع الدرجة التي تريد على خطّ وسط السماء ثم انظر على كم وقعت من الارتفاع فاحفظه ثم انظر الدائرة في الصفيحة التي يدور عليها رأس الحمل والميزان على كم وقعت من خطّ وسط السماء من الارتفاع فخذ فضل ما بينهما فما كان فهو ميل الدرجة إن شاء الله فإن كان ارتفاع الدرجة أكثر من ارتفاع رأس الحمل فالميل في الشمال وإن كان أقلّ فهو <في> الجنوب

[11a] **إذا أردت أن تعرف مواضع الكواكب الثابتة في الأصطرلاب** فضع رأس الكوكب المحدّد على خطّ وسط السماء ثم انظر أيّ برج وأيّ درجة وافق خطّ وسط السماء فهو موضع الكوكب من الطول فاعرفه إن شاء الله

[11b] **وإذا أردت أن تعرف عرض الكواكب الثابتة** فانظر ارتفاع الدرجة التي يمرّ الكوكب بها[29] على خطّ وسط السماء فاحفظه <ثم انظر أيضًا على كم وقع الكوكب على خطّ وسط السماء من الارتفاع> ثم خذ فضل بينهما فما كان فهو عرض الكوكب فإن كان ارتفاع ⟨85v⟩ رأس الكوكب أكثر من ارتفاع درجته فهو في الشمال وإن كان أقلّ فهو في الجنوب

[12a] **وإذا أردت أن تعرف مع أيّ درجة يطلع الكوكب** فضع رأسه المحدّد على مقنطرة المشرق ثم انظر أيّ برج وأيّ درجة وافق مقنطرة المشرق فمع تلك الدرجة يطلع الكوكب

[12b] **وإذا أردت أن تعلم مع أيّ درجة يغيب** فضع طرف الكوكب على مقنطرة المغرب ثم انظر أيّ برج وأيّ درجة وافق مقنطرة المغرب ففيها يغيب

[12c] **وإذا أردت أن تعرف مع أيّ درجة يجري الكوكب وكم ارتفاع نصف نهاره** فضع رأسه المحدّد على خطّ وسط السماء فما وافق فذلك ارتفاع نصف نهار الكوكب وهو أرفع ما يكون في ذلك البلد ثم أدر منطقة البروج فأيّ درجة وافق ذلك الارتفاع على خطّ وسط السماء فتلك الدرجة <هي> التي يجري الكوكب في مجراها

[13] **إذا أردت أن تعرف بعد الكوكب من خطّ الاستواء** فانظر ارتفاع رأس الكوكب وارتفاع مدار الحمل في وسط السماء فخذ فضل ما بينهما فهو بعده من خطّ الاستواء فإن كان رأس الكوكب داخل مدار الحمل ممّا يلي القطب فبعده في [الشمال][30] وإن كان خارجًا ممّا يلي الحجرة فبعده في الجنوب

[14] **إذا أردت أن تعرف قسي الكواكب لأيّ كوكب أحببتَ** فضع رأس الكوكب على مقنطرة المشرق ⟨86r⟩ ثم انظر مري[31] الأجزاء أين وقع فاحفظه ثم أدر رأس الكوكب حتى

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[29] يمرّ الكوكب بها] فيها الكوكب MS [30] Wormhole [31] مُوري MS [32] مُوري MS

تضعه على مقنطرة المغرب ثم انظر مري[32] الأجزاء أين وقع فاعدد من الموضع الأول إلى الثاني على مدار الكوكب فما كان فهو قوس نهاره

[15a] **إذا أردت أن تعرف الظلّ من الارتفاع وعَمَلَهُ كيف يُعمَل** فضع المري[33] الذي في العضادة على خمسة وأربعين من الارتفاع ثم انظر المري[34] للأجزاء أين تضع طرفه ممّا يُحاذي [35] الارتفاع من الدائرة التي في ظهر الأصطرلاب فتعلّم عليه ثم خُط منه خطًّا على زاوية قائمة إلى الخطّ الذي يُحاذي علاقة الأصطرلاب وهو قطر الدائرة وخطّ آخر على زاوية قائمة على الخطّ الذي يقطع خطّ[36] المشرق والمغرب ثم اقسم كلّ خطّ من هاذين على ١٢ قسمة مستوية فهذا عمله

[15b] **فإن أردت أن تعرف به العمل حتى تعرف الظلّ** فقس الشمس متى شئت ثم انظر المري[37] الذي كان يُحاذي الارتفاع على أيّ الخطّين وقع وعلى كم وقع من القسمة فإن كان الارتفاع أقلّ من ٤٥ فاعدد من الزاوية القائمة إلى المري[38] فما كان فهو قطر الظلّ وإن كان الارتفاع أكثر من ٤٥ فاعدد من الزاوية القائمة فما كان فهو الظلّ

[16] **إذا أردت أن تعرف عرض البلد** فقس الشمس نصف النهار أرفع ما يكون واحفظه ⟨86v⟩ ثم اقلب الأصطرلاب وضع درجة الشمس على خطّ وسط السماء فإن وافق مثل الارتفاع الذي خرج لك نصف النهار فأنت في ذلك الإقليم الذي عرضه مثل عرض تلك الصفيحة التي قست عليها وإن خالف الارتفاع ارتفاع درجة الشمس فخذ ما بين ارتفاع درجة الشمس وبين ارتفاع رأس الحمل في الصفيحة فاحفظه فإن كانت في ناحية الشمال فانقص هذا الذي حفظت من فضل ما بين الارتفاعين من الارتفاع الذي خرج لك بالقياس فما كان فهو ارتفاع الحمل في الإقليم الذي أنت فيه وإن كانت الشمس في الجنوب فزد الذي حفظت على ارتفاع القياس فما كان فهو ارتفاع الحمل في البلد الذي أنت فيه فما بلغ بعد الزيادة والنقصان[39] فانقصه من تسعين فما بقي فهو عرض البلد

[17] **إذا أردت أن تعرف الارتفاع من الطالع** فانظر درجة الطالع فضعها على مقنطرة المشرق ثم انظر درجة الشمس على كم وقعت من ارتفاع المقنطرات فما كان فهو ارتفاع تلك الساعة ثم انظر من قبل المشرق هو أو من قبل المغرب فاعرفه إن شاء اللّه

[18] **إذا أردت أن تعرف ما مضى من النهار من ساعةٍ من قبل الطالع** فضع درجة الطالع على مقنطرة المشرق ثم انظر نظير درجة الشمس إن كان بالنهار ⟨87r⟩ على كم وقع من

[33] المُوري MS [34] المُوري MS [35] يحادي MS, with a dot under the د to distinguish it from a ذ
[36] من MS (partially illegible due to a wormhole, but the initial م is clear, and the tail of the final ن is also visible). [37] المُوري MS [38] الموري MS [39] النقصان partly illegible (wormhole).

الساعات وكسورها على ما أريتُك فهو ما مضى من النهار من ساعة وإن كان ليلًا فانظر درجة الشمس على كم وقعت فهو ما مضى من اللّيل من ساعةٍ

[19] **إذا أردت أن تعرف ارتفاع الشمس من قبل الساعات** فضع نظير درجة الشمس على أيّ ساعة أحببتَ ثم انظر درجة الشمس على كم وقعت من الارتفاع <على>[40] المقنطرات من ناحية المشرق أو المغرب فهو الارتفاع

[20] **إذا أردت ارتفاع بعض الكواكب من قبل الطالع باللّيل ما كان منها فوق الأرض** فضع درجة الطالع على مقنطرة المشرق وإذا أردت ذلك من قبل الطالع وإن أردت من قبل الساعات فضع درجة الشمس على أيّ ساعة شئت ثم انظر إلى الكوكب الذي فوق الأرض ما وافق منها من الارتفاع من قبل المشرق والمغرب فهو ارتفاع ذلك الكوكب <في> تلك الساعة

[21] **إذا أردت أن تعرف من ارتفاع الكوكب ليل هو أو نهار** فقيل لك ارتفاع الكوكب عدد معلوم من ناحية المشرق أو المغرب فأردت أن تعلم ليلًا أو نهارًا فضع طرف الكوكب على مثل الارتفاع في الناحية التي هو فيها اعني الكوكب ثم انظر درجة الشمس فإن كان وقعت على شيء من المقنطرات فهو نهار وإن وقعت خلاف ذلك فهو ليل

[22a] ⟨87v⟩ **وإن أردت أن تحوّل الساعات المستوية إلى المعوجّة أو المعوجّة إلى المستوية** فضع نظير درجة الشمس على أيّ ساعة شئت ثم انظر مري[41] الأجزاء أين وقع فاحفظه ثم أدر نظير درجة الشمس[42] حتى تضعها على مقنطرة المغرب ثم انظر أين وقع مري الأجزاء فتأخذ عدد ما بينهما من الحجرة فما كان فهو ما دار من الفلك منذ طلعت الشمس إلى تلك الساعة فاقسمها على ١٥ فما كان فساعات مستوية

[22b] **إذا أردت أن تعرف الساعات المعوجّة من الساعات المستوية** فخذ الساعات المستوية فاضربها في ١٥ واحفظه ثم ضع نظير درجة الشمس على مقنطرة المغرب ثم انظر مري[43] الأجزاء أين وقع فاحفظه ثم أدر مري[44] الأجزاء على مدار الفلك حتى يزيله عن موضعه بقدر العدد الذي خرج لك من ضرب الساعات في ١٥ ثم انظر نظير درجة الشمس على كم وقعت من الساعات فهي الساعات المعوجّة فإن كان معك كسور فاعمل على درجة الشمس كما عملت على نظير درجة الشمس

[23] **إذا أردت أن تعرف البيوت الاثنى عشر إذا عرفت الطالع والأوتاد** { وأردت أن تعرف البيوت الاثنى عشر } فخذ نظير درجة الطالع وضعها ⟨88r⟩ على ساعتين من ناحية

[40] Two horizontal strokes are written at the end of the line after الارتفاع , perhaps to indicate a word the copyist could not read. [41] مُوري MS [42] نظير درجة الشمس] درجة نظير درجة الشمس MS [43] مُوري MS [44] مُوري MS [45] انظر written above the line MS

المغرب ثم انظر[45] خطّ وسط السماء ما قطع من البروج فهو بيت الرجاء ثم ضع نظير درجة الطالع على أربع ساعات ثم انظر خطّ وسط السماء أيّ شيء قطع من البروج فهو بيت الأعداء ثم ضع نظير درجة الطالع على ستّ ساعات ثم انظر خطّ وسط السماء ما قطع فهو الطالع فإن وافق الطالع فقد أصبتَ وإن خالف فقد أخطأتَ فأعدّ عملك ثم ضع الطالع على عشر ساعات ممّا يلي المغرب وإن شئت على ساعتين ممّا يلي المشرق ثم انظر خط وسط السماء ما قطع من البروج والدرج فهو بيت السفر ثم ضع الطالع على ثمان ساعات ممّا يلي المغرب ثم انظر ما قطع وسط السماء من البروج <فهو> بيت الثامن وبيت المال نظير بيت الثامن وبيت الأخوة نظير بيت السفر وبيت الآباء نظير وسط السماء وبيت الولد نظير بيت الرجاء وبيت المرض نظير بيت الأعداء والسابع نظير الطالع وإن أحببت أن تعرفه من الأصطرلاب فإذا عرفت بيتًا من هذه البيوت على خطّ وسط السماء فما قطع وتد [الأرض][46] فهو نظير ذلك البيت إن شاء الله تعالى

[24] **معرفة مطرح الشعاع بالأصطرلاب**[47] تضع جزء أيّ درجة شئتَ على أول مقنطرةٍ ثم تعلّم على رأس الجدي ⟨88v⟩ ثم زد على العلامة ٦٠ ثم أرفع رأس الجدي الذي زدتَ عليه فما كان الطالع من الأجزاء على مقنطرة المشرق فهو نور التسديس وكذلك التربيع والتثليث والمقابلة لدرجة الطالع هي درجة الغارب[48]

[25] **تحويل سني المواليد بالأصطرلاب** إذا أردت علم ذلك فانظر ما مضى من سني المواليد التامّة فاضربها في ٩٣ درجة ودقيقتين فما اجتمع ألقِ منه دَوْرًا إن كان فيه وما بقي فاحفظه ثم أدر العنكبوت حتى يوافق طالع المولد <بمقنطرة المشرق> { أو خطًّا من خطوط المشرق } ثم اعرف الموضع الذي يقابل المري[49] من خطوط الحجرة ثم زد ما حفظتَ على موضع المري [50] فالموضع الذي انتهى إليه العدد فصيّر المري بحياله[51] فما كان على خطّ المشرق فهو طالع السنة للمولد

[26a] **وإن أردت أن تعرف طالع السنة بالأصطرلاب** فانظر طالع السنة الماضية فضع ذلك الجزء على مقنطرة المشرق فما كان فانظره وزد عليه ٩٣ فما كان فهو الطالع إن شاء الله عزّ وجلّ[52]

[26b] **وإن أردت أن تعرف طالع الربع الأول** فضع طالع السنة على مقنطرة المشرق[53] ثم انظر مري الأجزاء أين وقع من عدد درج الحجرة فزد على ذلك ٤٩ ثم أدر مري[54] الأجزاء إلى ذلك العدد الذي زدتَ عليه ⟨89r⟩ ثم انظر إلى مقنطرة المشرق وما قطعت من البروج

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[46] Wormhole [47] **بالأُصطرلاب** MS [48] لدرجة الطالع هي درجة الغارب] درجة الطالع بدرجة الغارب MS

[49] الموري MS [50] الموري MS [51] نخياله MS [52] عزّ وجلّ] عزّرجل MS [53] Partly illegible (wormhole).

[54] مَرِي MS

والدرج فهو طالع الربع الأول وزد على الربع الأول زيادته فيكون الربع الثاني وكذلك تعمل بكلّ ربع أردت إن شاء اللّه تعالى

[26c] ⟨89v:7-11⟩ **ووجدتُ في نسخةٍ أخرى** إذا أردت أن تعلم طالع السنة تزيد على طالع السنة الماضية ٩٣ درجة ١٥ دقيقة وبين طالع السنة وبين الربع الأول ٤٩ درجة وثُلثي دقيقة وبين طالع السنة والربع الثاني قعج ن وبين طالع السنة والربع الثالث قعا مه فاعلم ذلك إن شاء اللّه تعالى

[27] ⟨89r (cont.)⟩ **معرفة المدينة التي فيها جنوبية أو شمالية** انظر أكثرهما[55] ارتفاعًا[56] هي أقربهما[57] إلى الجنوب وأقلّهما[58] ارتفاعًا[59] أقربهما[60] إلى الشمال **بيان ذلك** إن قستَ الشمس بالريّ حين دخلت أول الجزء من الحمل فما كان ٥٣ درجة ثم قسه بالكوفة فكان ٥٨[61] في مثل ذلك اليوم والذي بينهما خمس درج فأكثرهما[62] ارتفاعًا[63] هي أقربهما[64] إلى الجنوب فقس كذلك إن شاء اللّه تعالى وبه القوة

[28a] **معرفة طلوع الفجر ومغيب الشفق** تضع جزء الشمس على ١٨[65] من ارتفاع[66] المقنطرات من ناحية المغرب ثم انظر على كم وقعت <نظير> درجة الشمس من الساعات فما كان ففي تلك الساعة يطلع الفجر فاعلم ذلك إن شاء اللّه

[28b] **مغيب الشفق** إذا أردت أن تعرف متى يغيب الشفق فضع نظير درجة الشمس على ١٨[67] من الارتفاع من ناحية المشرق ثم انظر على كم وقعت درجة الشمس من الساعات ففي تلك الساعة يغيب الشفق

[28c] ⟨89v:1–6⟩ **معرفة وقت الظهر والعصر** إذا أردت ذلك بالارتفاع فارصد الشمس حتى تقف على خط وسط السماء ثم انقص من الارتفاع سبع درج فهو الظهر وأمّا وقت العصر خذ ارتفاع نصف نهار يومك فانقصه من تسعين فما بقي خذ عُشره وزد العُشر على نصف ارتفاع نصف نهار يومك فما خرج فهو ارتفاع وقت العصر إن شاء اللّه

[28d] ⟨90r:11-17⟩ <**آخر**> **وقت الظهر** إذا أردت أن تعرف آخر وقت الظهر فضع درجة الشمس على يد من السمت من ناحية المغرب ثم انظر على كم وقعت من ارتفاع المقنطرات فما [كان] فهو ارتفاع آخر وقت الظهر من ناحية المغرب

[28e] **فإذا أردت آخر وقت العصر** فانقص ارتفاع نصف النهار من ٩٠ أبدًا فما بقي فخذ عُشره فما كان فزده على ارتفاع نصف النهار فما بلغ فهو ارتفاع آخر وقت العصر فاعلم ذلك

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55 أكثرهم MS 56 ارتفاع MS 57 أقربهم MS 58 وأقلّهم MS 59 ارتفاع MS 60 أقربهم MS 61 Looks like a ٥٦ 62 فأكثرهم MS 63 ارتفاع MS 64 أقربهم MS 65 Looks like a ١٦ 66 الارتفاع MS 67 Looks like a ١٦ 68 معرفة السمت] *bis* MS

[29] ⟨89v:12–17⟩ **معرفة السمت**[68] **من الأصطرلاب** تأخذ الارتفاع ثم ضع جزء الشمس على مثل الارتفاع الذي أصبت من جهة المشرق أو المغرب فإذا فعلت ذلك فانظر ما وافا جزء الشمس من الخطوط المرسومة للسمت فما كان فهو السمت في ذلك الوقت الذي أخذتَ له القياس فإن كان العدد الذي أصبت آخذًا[69] من مشرق الاستواء ⟨90r:1–10⟩ إلى تحت الأرض فالسمت فيما بين[70] مشرق الاستواء والشمال وإن كان الذي أصبت للسمت آخذًا[71] من مشرق الاستواء إلى وسط السماء فالسمت فيما بين مشرق <الاستواء و> الجنوب وإن كان السمت الذي أصبت من[72] وسط السماء إلى مغرب الاستواء فالسمت[73] بين الجنوب ومغرب الاستواء وإن كان السمت من[74] مغرب الاستواء إلى تحت الأرض فالسمت[75] فيما بين مغرب الاستواء والشمال

فليكن استعمالك للسمت إذا أردت استعماله والاستخراج به <من> خطّ نصف النهار على هذه الجهة وخطّ مشرق الاستواء من خطوط السمت هو الخطّ الفاصل لها فيما بين الواوين [من][76] المشرق وخطّ مغرب الاستواء من المغرب هو الخطّ الفاصل <لها> فيما بين الواوين أيضًا

[30a] ⟨90v⟩ **معرفة وقت طلوع القمر** إذا أردت ذلك فاعرف جزء الشمس وجزء القمر فإن كان بين القمر وبين الشمس أقلّ من ١٨٠ جزءًا فاقسمه على أزمان الساعات للنهار فما خرج من الساعات فهي ساعات مضت من النهار إلى وقت طلوعه وإن كان بين الشمس وبينه أكثر من مائة وثمانين فاضرب أزمان ساعات النهار في ١٢ وألقيه من البعد الذي بينهما وما بقي فاقسمه على ساعات اللّيل فما كان فهو ساعات تمضى من اللّيل إلى طلوعه ويكون ما يعمل في البعد الذي بين الشمس والقمر للقسمة بدرج[77] المطلعة وأخذك لجزؤي القمر والشمس إن كان الذي بين القمر والشمس أقلّ من نصف قوس النهار وكان أقرب إلى الطلوع فقوّمهما لطلوع الشمس وإن كان أقرب إلى نصف النهار فقوّمهما لنصف النهار وإن كان أقرب إلى غروب الشمس فقوّمهما لغروب الشمس وكذلك فافعل في اللّيل إن كان أكثر من قوس النهار وأقلّ من <قوس النهار و> نصف قوس اللّيل { بقدر أقلّ من نصف قوس اللّيل[78] } وإن كان أقرب إلى أول اللّيل فقوّمهما لنصف اللّيل وإن كان أقرب[79] إلى طلوع الشمس فللغد[80] وهذا هو التقريب وإذا أردت أن[81] تعرفه بألطف من هذا فقوّم الشمس والقمر على الزمان ⟨91r⟩ الذي يخرج لك من هذه الساعات لليلٍ أو نهارٍ ثم اعمل به كالعمل الأول

[30b] **فإن أردت أن تعلم كم يمكث** إذا كان يدخل اللّيل وهو طالع فألقِ البعد الذي بينه

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69 اخذ MS 70 بُنَ MS 71 اخذ MS 72 فيما بين MS 73 والسمت MS 74 فيما بين MS 75 والسمت MS 76 Wormhole 77 بالدرج MS 78 بقدر أقلّ من نصف قوس اللّيل] Superfluous words. 79 إلى أول ... أقرب] marg. MS 80 للغد MS 81 *bis* MS

وبين قوس النهار <من قوس نهار القمر> وما بقي فاقسمه على أزمان ساعات اللّيل فما خرج فهو ساعات مكثه <وهو> طالع فاعلم ذلك إن شاء اللّه تعالى

[30c] **معرفة الطالع بالأصطرلاب من القمر** تأخذ ارتفاع القمر وتعرف ناحية المشرق هو أو ناحية المغرب فاحسب طول القمر تلك الساعة وعرضه فإن كان عرض القمر في الشمال فانقص من ارتفاع القمر مثل عرض القمر[82] وإن كان عرض القمر في الجنوب فزد على ارتفاع القمر مثل عرض القمر فما كان ارتفاع القمر بعد ذلك <فاحفظه> فضع جزء القمر من برجه على مثل ذلك الارتفاع من ناحية المشرق إن كان القمر حيث أخذت ارتفاعه من ناحية المشرق وإن كان من ناحية المغرب فمن ناحية المغرب مثل ما تعمل بالشمس فالجزء من البرج الذي يكون على خطّ المشرق هو الطالع واعلم أنّ القمر إذا جاوز الرأس إلى أن يُجامع الذنب عرضه في الشمال وإذا جاوز الذنب إلى أن يجامع الرأس فعرضه في الجنوب ⟨91v⟩ واليمني[83] (؟) هو الجنوب والجوفي[84] (؟) هو الشمال فاعلم ذلك إن شاء اللّه

[31] **إذا أردت أن تعرف انتصاف النهار في المدائن** تأخذ الشمس بثقبي العضادة نصف النهار في احدى المدينتين ثم تأخذها في الأخرى في مثل ذلك اليوم ثم تلقي الأقلّ من الأكثر فما خرج بينهما من الفضل فكلّ ١٥ منه ساعة مستوية[85] وأكثرهما هي أقربهما إلى المشرق

[31b] **مثال**[86] **ذلك** طول بغداد ٧٠ وطول دمشق ٦٠ يتهي ثلثي ساعةٍ

Text 3: On a compass for finding the prayer-times — $\mathcal{B}$: 91v–92r, 94r (table)

عمل بركار يُعرَف به الأوقات للصلوة ويُقاس به الظلّ

إذا أردت عمل ما ذكرنا فاتّخذ – عليّ اسم اللّه – بيكارًا[1] إن شئت من عاج وإن شئت من شبه أيّ د...[2] شئت وربّعه تربيعًا مستويًا مُهندَسًا شديد الاستواء من المَقبِض إلى موضع القلمين واعمل له قلمين من حديدٍ واقسم عرض البيكار من ناحية المغرب بأربعة أجزاء وطوله أربعة أجزاء متساوية واكتب عليها البروج من الحمل إلى السنبلة[3] على التأليف واخرج حسابه من الجدول واكتب بحذاء كل برج ما له من الحساب كما تراه مصوّرًا ثم اقسم أيضًا ناحية المشرق من البركار مثله سواء واكتب عليها[4] البروج من الميزان ⟨92r⟩ إلى الحوت واكتب

[82] Wormhole [83] المى MS [84] الحَربا MS [85] فكلّ ١٥ منه ساعة مستوية] فكلّ ١٥ منه يه ساعة مستوية MS [86] مثل MS [1] بيكار MS [2] Partly illegible (wormhole). The last letter could be a ك [3] إلى السنبلة] Partly illegible (wormhole). [4] Partly illegible (wormhole). [5] Above the line MS

بحذاء كلّ برج[5] حسابه كما عملت أوّلًا ثم اقسم من ناحية الشمال اعني وجه البيكار والجنوب جميعًا كلّ واحدٍ باثنى عشر جزءًا واكتب عليها العدد وابدأ بكتابة العدد من ناحية قلمي البيكار فإذا فرغت من هذا كلّه فسمّر البيكار بمِسمارٍ حديدٍ ويكون في رأسي المسمار فلسين كما تراه مصوّرًا[6] فاعلم ذلك

⟨94r⟩ < جدول أول الظهر وأول العصر وآخره لكل ست درجة ست درجة > بعرض لج [a]

الشمال

المغرب

أسماء البروج	أول الظهر	أول العصر	آخر العصر	العدد
السرطان / الجوزا	٢	يج	كه	• [b]
	٢	يج	كه	و
	٢	يد	كه	يب
	٢	يد	كه	يح
	٢	يد	كه	كد
	٢	يد	كه	ل
الأسد / الثور	٢	يد	كو	و
	٣	يه	كز	يب
	٣	يو	كح	يح
	٤	يو	كح	كد
	٤	يز	كح	ل
السنبلة / الحمل	٥	يز	كط	و
	٦	يز	كط	يب
	٦	يح	لا	يح
	٧	يط	لا	كد
	٨	ك	لب	ل

الجنوب

المشرق

أسماء البروج	أول الظهر	أول العصر	آخر العصر	العدد
الميزان / الحوت				
	٨	ك	لب	و
	٩	كا	لد	يب
	١٠	كب	لد	يح
	١١	كج	لو	كد
	١٢	كد	لو	ل
العقرب / الدلو	١٢	كه	لو	و
	١٣	كه	لح	يب
	١٤	٢٦	لط	يح
	١٦	كح	لط	كد
	١٦	كح	ما	ل
القوس / الجدي	١٧	كط	ما	و
	١٧	كط	مب	يب
	١٨	لا	مج	يح
	١٨	لا	مد	كد
	١٨	لا	مد	ل

[a] لح MS [b] ا MS

[**في الهامش**] إذا أردت أن تعرف ظل نصف <نهار> يومك فانقص قوس نصف النهار من مطالع ما بين أول السرطان إلى آخر القوس وما بقي اقسمه على يه فما خرج فهو ظل نصف نهار يومك إن شاء اللّه تعالى

صفة العمل بهذا البيكار

إذا أردت أن تعرف أوقات الصلوة بهذا البيكار الذي وصفنا عمله فاعمد إلى مكانٍ مستوٍ[7] من الأرض وضُمّ البيكار حتى يلتقي القلمان ثم اغرز قلمي البيكار في الأرض حتى تُغيبه ثم

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[6] كما تراه مصوّرًا] Marg. MS [7] مستوي MS [8] Partly illegible (wormhole).

علّم على طرفَي[8] الظلّ الذي خرج من البيكار في أيّ وقتٍ كنتَ ثم اقلع البيكار من موضعه وامسح به الظلّ بالأصابع المقسومة[9] على البيكار وهو اثنا عشر أصابعًا فما خرج لك من جملة الأصابع فاحفظه ثم انظر إلى ظلّ الأوقات الذي على البيكار بحذاء البرج الذي فيه[10] الشمس فإن وافق الظلّ الذي حفظت الظلّ الذي على البيكار فهو وقت تلك الصلاة فإن نقص أو زاد فترصده قليلًا[11] حتى يَستوفي ظلّك الذي لتلك الصلوة على ما في البيكار إن شاء اللّه

Text 4: On a plate for finding the times of moonrise and moonset — $\mathcal{B}$: 92r–93r

عمل صفيحة يُوخذ بها الارتفاع ويُعرف بها طلوع ⟨92v⟩ القمر

في كلّ ليلة ومتى يغيب وكم يمكث إذا طلع

إذا أردت عمل ما وصفنا فاتّخذ، عليّ بركة اللّه!، صفيحةً قويةً ثخينةً على قدر ما تريد ثم خُطّ عليها خطّين[1] يقاطعان على المركز على زاوية قائمة واكتب عليها جهاتها الأربع المشرق والمغرب والجنوب والشمال ثم أدر في ناحية الجنوب ثلاث دوائر الدائرة الأولى وهي دائرة الخمسات اقسمها من المشرق إلى المغرب بستّة وثلاثين جزءًا واكتب عليها دائرة الخمسات وابدأ بكتابتك[2] الخمسات من المشرق والمغرب جميعًا حتى يلتقي ص̄ و ص̄ في وسط السماء والدائرةلثانية وهي دائرة الارتفاع اقسمها بثمانية وثمانين جزءًا والدائرةلثالثة وهي دائرة عدد اللّيالي اقسمها بثمانية وعشرين جزءًا واكتب[3] عليها[4] من آ إلى كح̄ ابدأ بالكتابة من المغرب إلى المشرق كما تراه في الصفيحة مكتوبٌ فإذا فرغت من ناحية الجنوب فأدر دائرةً واسعةً في ناحية الشمال واقسمها كح̄ جزءًا واكتب عليها الحساب على ما في الجدول وابدأ بالكتابة من المشرق إلى المغرب كما تراه مكتوبٌ في الصفيحة ثم اعمل لها عضادة وركبها عليها ركيبًا مستويًا واعمل بها إن شاء اللّه تعالى وبه القوة

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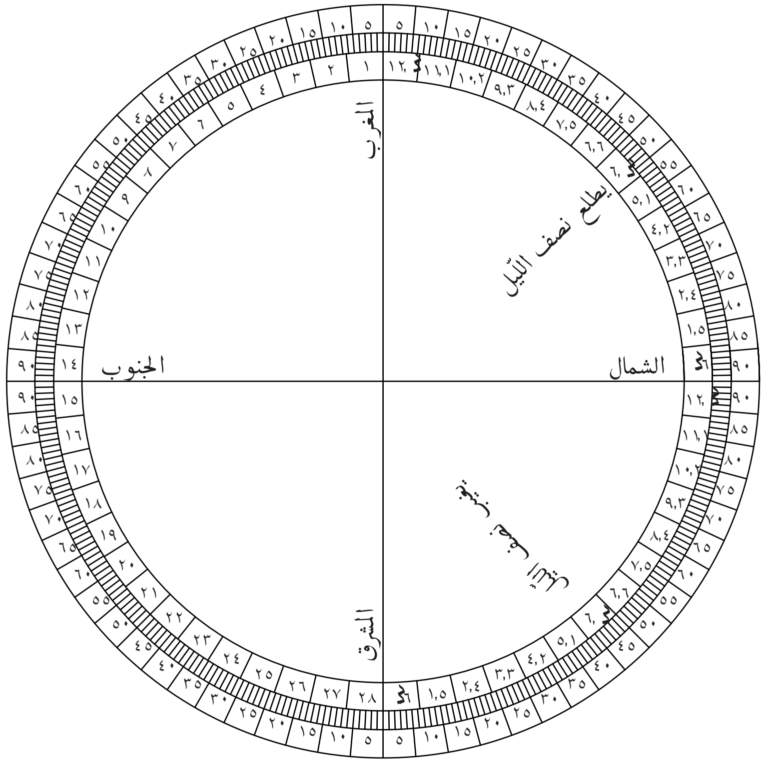
[9] المقسوم MS [10] الذي فيه] Partly illegible (wormhole). [11] قليل MS [1] خُطين MS [2] بكتابك MS
[3] جزءًا واكتب] Partly illegible (wormhole). [4] على MS



Text 5: On the species of astrolabes — $\mathcal{B}$: 96r

بـــــاب معرفة العلّة التي سُمّي بها الأصطرلاب تامًا

أو سمّي نصفًا وثلثًا وخمسًا وسُدسًا وغير ذلك من الأسماء

أمّا الرسوم التي لا يقع فيها اختلاف في جميع الأصطرلابات فهي دوائر المدارات اعني مدار السرطان والحمل والجدي وخطّ نصف النهار وخطّ الاستواء فإنّ هذه الخطوط كلّها في جميع الأصطرلابات لا يقع فيها خلافٌ[5] البتّةَ وإنّما تختلف دوائر المقنطرات لأنّها تكون في التامّ ٩٠ والذي يكون فيه ٤٥ نصفٌ والذي يكون فيه ٣٠ ثُلثٌ لأنّ لكل ثلاثة أجزاء دائرةً والذي يسمّى خُمسٌ بين كلّ دائرتين خمسة أجزاء وإذا كانت الدوائر خمسة عشر سُمّي سدسًا وإذا كانت الدوائر ٩ سُمّي عُشرًا لأنّ الأصطرلاب يكون بعد ما بين الدائرتين عشرة وعلى عدد ذلك تقسم بروجه

[5] خلافًا MS

Text 6: On projecting the rays with the astrolabe — $\mathcal{B}$: 96r–96v

مطرح الشعاع بالأصطرلاب

انظر الكوكب[6] <الذي> أردت مطرح شعاعه[7] فخذ درجته فضعها على مقنطرة الأفق فإذا أردت [أن] تطرح شعاعه في تسديس الأيسر تعلّم على رأس الجدي ثم أزله عن موضعه ٦٠ درجة ⟨96v⟩ ثم انظر ما وافق مقنطرة الأفق من البرج والدرجة فهو موضع تسديسه الأيسر وإن أردت تسديسه الأيمن فأدر[8] رأس الجدي إلى خلف عن موضعه ستّين فما وافا مقنطرة المشرق فهو موضع شعاعه الأيمن وإن أردت التثليث زد مائة وعشرين والتربيع ٩٠ وتفعل بالأيمن والأيسر مثل الأوّل إن شاء الله تعالى

Text 7: Ptolemy's definition of the terrestrial zones — $\mathcal{B}$: 96v

قسمة بطلميوس : الطرائق الخمس

الطريقة الأولى التي نحو الشمال ٣٦ جزءًا وط دقائق والثانية ٣٠ والثالثة التي تستوي فيها اللّيل والنهار ٤٧ جزءًا و٥١ دقيقةً نحو الشمال ومثل ذلك نحو الجنوب

والرابعة ٣٠ والخامسة التي ......[9] لا تُرى في الجنوب ٣٦ <جزءًا> وط[10] دقائق فجميع ذلك مائة وثمانين جزءًا

Text 8: On the sine quadrant — $\mathcal{B}$: 96v–97v

عمل ربع يُستخرج منه الجيب والميل وما مضى من النهار من ساعة

إذا أردت أن تعمل هذا الربع فاتّخذ على بركة اللّٰه[1] وعونه ربعًا من [...] يكون[2] على زاوية[3] قائمة مستخرج من دائرة صفيحة القسمة ثم اقسمه بتسعين جزءًا ثم اقسم من المركز إلى حرف أجزاء ⟨97r⟩ التسعين بمائة وخمسين جزءًا أجزاءً متساويةً وهو الجيب ثم علّق فيه خيط وشاقول ثم تعمل إلى الجيب جيب درجة درجة كما هو في جدول معمول فيُستخرَج

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[6] انظر الكوكب] Wormhole (only انظـ ... كب is legible). [7] Vocalized شُعاعَهُ MS [8] فدر MS [9] Wormhole (only لسار بعـ ... ـن is visible). [10] ط ا MS [1] اللّٰه marg. MS [2] يكون [...]] Partly illegible (wormhole). The first word seems to begin with سـ; the last two letters of يكون are legible. [3] زواية MS

بالتصحيح من الجدول المُوقَّع عليه جدول الجيب ومعرفة ذلك أن تأخذ جيب خمسة من الارتفاع فتنظر كم له من الجيب فتخطط في الربع على الصفيحة كما ترى مصوّرًا فاعلم ذلك إن شاء اللّه تعالى

صفة العمل بهذا الربع إذا عُمِل

إذا أردت أن تعرف ميل كلّ درجة فاعمل كما أصف لك فكُنّا[4] أردنا أن[5] نستخرج ميل الحمل فإنّا نضع الخيط على حرف ثلاثين من الارتفاع ثم تنظر أيّ موضع وقع الخيط من الدائرة الحمراء وهي دائرة الميل[6] ثم تأخذ فيه على السمت فنجد الخيط الذي أخذنا فيه قد وقع على خمسة وعشرين درجة ودقائق[7] من درج التسعين فذلك ميل الحمل وكذلك إذا أردت ميل الثور تأخذ ما بحيال ٦٠ من الارتفاع تعمل به كذلك وميل الجوزاء هو جزء التسعين وهو الميل كلّه وميل آخر السرطان مثل ميل أوّل الجوزاء وكذلك العمل بالباقي

فإذا أردت أن تعرف ما مضى من النهار من ساعةٍ ⟨97v⟩ فانظر كم ارتفاع نصف نهار يومك فكأنّه كان ٦٠ فوجدناه يُوافي الدائرة الخامسة اعني الخطّ الذي خرج من طرف التسعين الذي هو الجيب من دائرة الأجزاء وهي التي فيها ١٣٠ من الجيب وكأنّ الارتفاع وقت القياس ٣٠ فوافق الخيط على الدائرة الخامسة في موضعٍ منها فأخذنا سمته إلى موضع الارتفاع فوجدناه على خمسة وعشرين ودقائق فعلمنا[8] أنّه قد مضى من النهار ساعة وثلثين وكسر لأنّ كلّ ١٥ من الارتفاع ساعة وذلك لأوّل النهار فإن كان القياس بعد الزوال فما بقي من النهار من ساعةٍ

فإن أردت أن تعمل من جيب[9] ستّين فاقسم جيب الربع على ستّين

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[4] Partly illegible (wormhole). [5] أنّ MS [6] الحمل MS [7] Only ود ... is legible (wormhole); the word دقائق is however attested a few lines below. [8] فعلنا MS [9] Only ـب ... is legible (wormhole).

Text 9: On finding the meridian with the astrolabe — $\mathcal{A}$: 198v–199r

ظرائف من عمل محمد بن موسى الخوارزمي — معرفة السمت بالأصطرلاب

إذا أردت أن تعرف السمت بالأصطرلاب فقس الشمس متى شئت ثم انظر ما خرج لك من الارتفاع فضع درجة السمش على مثله من المقنطرات ثم انظر أيّ خطّ يوافي ذلك الارتفاع من خطوط السمت فما أصبت فهو سمت تلك الساعة

فإن أردت أن تعرف خطّ نصف النهار وكانت الشمس شرقية جنوبية فعدّ مثل ذلك السمت من الربع الذي أخذت به الارتفاع وضع عليه طرف العضادة ثم صيّر ظهر الأصطرلاب موازيًا للأفق وأدره يمنةً ويسرةً حتى يقع ظلّ الكرسي على ظهر العضادة أو تدخل الشعاع من الثقب فتقع على الخطّ الذي في وسط العضادة[10] فإذا رأيته كذلك فإنّ خطّ نصف النهار هو قطر ظهر الأصطرلاب الذي فيه العلاقة وافعل مثل ذلك إن كانت الشمس في المغرب والشمال غير أنّ العلاقة تقع في هذا العمل إلى ناحية الشمال وفي العمل الأوّل إلى ناحية الجنوب ⟨199r⟩

وإن كانت[11] الشمس شرقية شمالية عددت [مثل ذلك السمت من] الربع [الآخر ؟] ...[12] عن يمين الربع الذي تأخذ منه الارتفاع وليكن عددك من أسفل إلى ناحية العلاقة ثم ضع طرف العضادة على ذلك العدد وصيّر[13] ظهر الأصطرلاب أيضًا موازيًا للأفق فتديره يمنةً ويسرةً حتى تستظل العضادة بالكرسي أو تدخل الشعاع من الثقب إلى الخط الأوسط فإذا كان كذلك فإنّ خطّ نصف النهار يقع على القطر الذي فيه العلاقة والعلاقة في ناحية الشمال وكذلك تعمل إذا كانت الشمس غربية جنوبية غير أنّ العلاقة تقع إلى ناحية الجنوب

ونتبيّن لك الشمس شمالية أم جنوبية من قوس السمت الذي يبتدئ من مطلع الحمل ويجوز على سمت الرأس وتنتهي إلى نقطة مغرب الحمل فإن كانت الشمس فيما بين هذه القوس وناحية مركز الأصطرلاب فهي شمالية إن كانت في المشرق وإن كانت في المغرب أيضًا وإن كانت خارجة من هذه القوس فيما بينها وبين حرف الأصطرلاب فإنّها جنوبية كانت في المشرق أو في المغرب وهذه الصفة هي للأصطرلاب الذي يكتب <عليه> سمتها من قوس سمت مطلع الحمل إلى وسط السماء وإلى وتد الأرض تسعين تسعين من الناحيتين

وأمّا الأصطرلاب الذي يبتدئ <عليه> بعدد السمت من خطّ وسط السماء ويتهي إلى وتد الأرض مائة وثمانين من الناحيتين جميعًا اعني المشرق والمغرب فإنّك إذا أخذت ما خرج

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[10] Smudged MS. Only العـ ··· ده is visible. [11] وإن كانت] Smudged MS. Only ··· انت is visible. [12] The second half of the first line is barely legible on the available photograph. [13] حتى تصيّر MS

لك بالسمت فتحفظه فإن كانت الشمس شرقية كيف كانت في الشمال أو الجنوب فإنّك تعدّ ما [14] حفظت يمنةً عن ابتداء الارتفاع وتضع العضادة عليه وتسامت به الشمس على ما[15] وصفنا

Text 10: On the horary quadrant — $\mathcal{A}$: 196v–197r

⟨196v⟩ **صنعة الربع للساعات**

إذا أردت ذلك فخذ ربع دائرة وصيّره فصلين للارتفاع ثم خطّ في طرفي الربع خطّين يجوزان زاويةً قائمةً وموضع الزاوية هو موضع الثقب الذي يكون فيه الخيط الذي به يعرف الارتفاع فإذا أردت قسمة الساعات فاقسم مقدار ثلاثة أرباع الخطّ القائم على حرف الربع بثلاثة عشر قسمًا ثم ضع البركار في مركز الربع وافتحه إلى كلّ واحد من العلامات الثلاثة عشر ثم أدر به دوائرًا يلحق بالخطّين المقسومين المستقيمين فيكون أوسع القسي لرأس الجدي وأضيقها لرأس السرطان فإذا أبدأت من أعلاها فإنّ أوّل القسي للسرطان والذي يليه لنصف والذي يلي ذلك لأسد ثم نصّفه إلى أن تبلغ الجدي ثم ترجع في الخطوط فيصير نصف الجدي مثل نصف القوس كذلك حتى يتنهي إلى آخر الجوزاء ثم تبتدئ بالسرطان إن شاء اللّه

وقد وضعت لك جدولًا لارتفاع الساعات[1] في البروج وأنصافها فاعلم عليه

فأمّا عملنا ارتفاع الساعات فإذا أردت ذلك فخذ جيب السرطان في الإقليم الذي أنت فيه فاحفظه ثم خذ الكردجة الأولى من الجيب فاضربها في جيب رأس السرطان واقسمه على مائة وخمسين فما ⟨197r⟩ [...] قوع (؟) فهو جيبٌ فصيّره قوسًا فما كان[2] فهو ارتفاع الساعة الأولى من السرطان واحفظه

ثم خذ الكردجة الأولى والثانية فاضربها في جيب نصف النهار واقسمها على مائة وخمسين فما خرج فقوّسه فما خرج فهو ارتفاع الساعة الثانية

ثم خذ الكردجة الأولى والثانية والثالثة فافعل بها كذلك فما خرج فهو ارتفاع ثلاث ساعات وكذلك الرابعة والخامسة والسادسة وافعل في غيره كما فعلت بالسرطان وكذلك لجميع البروج كلّها

وإن أحببت أيضًا فخذ خمسة عشر درجة فصيّرها جيبًا فما خرج فاضربه في جيب ارتفاع نصف نهار السرطان فما بلغ فاقسمه على مائة وخمسين فما خرج فاجعله قوسًا فما خرج من القوس فهو ارتفاع ساعة من ساعات السرطان ثم خذ ثلاثين فافعل بها مثل ذلك إلى تسعين فما خرج فهو ساعات السرطان ثم افعل بسائر البروج كذلك

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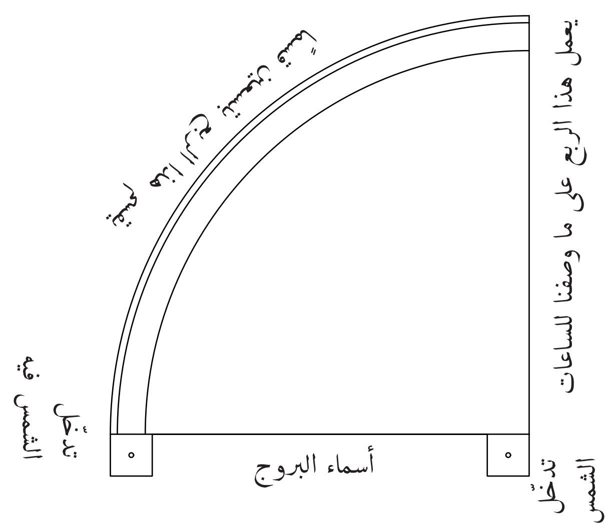
[14] Illegible MS [15] Illegible MS [1] لارتفاع الساعات] للارتفاع الساعات MS [2] فصيّره قوسًا فما كان] Smudged MS

وقد عملت الجدول والصورة فافهم ذلك

جدول الربع

أسماء البروج	الساعة الأولة	الثانية	الثالثة	الرابعة	الخامسة	السادسة
السرطان	يد د	كط د	مد د	نط د	عج د	فا د
نصف	يد د	كط د	مد د	نح د	عب د	ف د
الأسد	يد د	كط د	مد د	نز د	ع د	عز د
نصف	يد د	كح د	مج د	نو د	سز د	عج د
السنبلة	يد د	كز د	ما د	نج د	سج د	سط د
نصف	يج د	كو د	لط د	ن د	نط د	سج د
الميزان	يب د	كه د	لو د	مز د	ند د	نز د
نصف	يب د	كج د	لج د	مب د	مح د	نا د
العقرب	يا د	كا د	ل د	لح د	مج د	مه د
نصف	ي د	يط د	كح د	له د	لط د	ما د
القوس	ط د	يز د	كه د	لا د	له د	لو د
نصف	ح د	يو د	كج د	كط د	لج د	لد د
الجدي	ح د	يو د	كج د	كح د	لب د	لج د



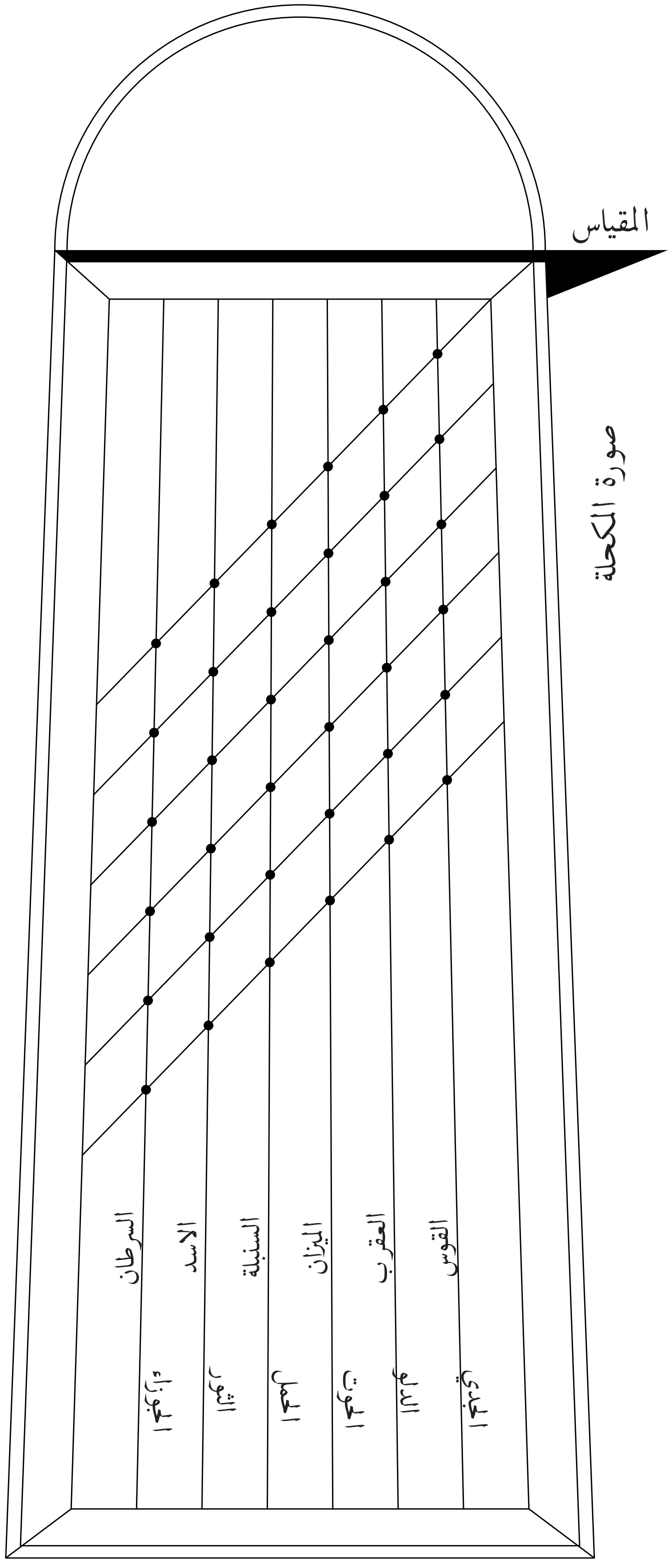
Text 11: On a portable sundial (*mukḥula*) — $\mathcal{A}$: 192r

عمل المكحلة للساعات وهو يصلح للعمود والسوط والعكّازة

إذا أردت ذلك فاتّخذ آلة من خشب أو شبه وليكن رأس هذا المقياس خمسة أسداس أسفله ثمّ اقسمه عرضًا[3] لبرج برج بستّة أقسام وإن شئت فلنصف نصف ثمّ خذ طول هذه الآلة فخطّ خطًّا على لوح وضعه ناحيةً وليكن الخط بطول المقياس واقسمه بثلاثين قسمًا متساوية وهي مسطرة الظلّ ثم خذ من الحساب الذي في الجدول ساعات برج برج من المسطرة المقسومة وضع رجل البركار من فوق عند المقياس حتى تستوفى الساعات للبروج كلّها ثم اتّخذ [م]قياسًا من شبه على ما ترى ويكون خروجه من حرف الآلة خمسة أجزاء محدّد الرأس شبه مقياس الرخامة يدور عليه تحت العلاقة التي تُعلَق بها المقياس فإذا أردت أن تعلم ما مضا من النهار من ساعة فاعرف موضع الشمس وعلّق الآلة واستقبل بالخطّ الذي فيه الشمس وتكون قد كتبت أسماء البروج على الخطوط وصيّر المقياس فوقه فإنّ الظلّ يقع على ما مضا من النهار من ساعة إن شاء اللّه

الجدي	القوس الدلو	العقرب الحوت	الميزان الحمل	السنبلة الثور	الاسد الجوزاء	السرطان	الساعات
٠ مط	٠ نح	—	ا و	ا يا	ا يب	ا يج	ا
ا كط	ا كد	—	ب يح	ب لج	ب لو	ب لح	ب
ب ط	ب كب	—	ج لط	د يط	د لح	د مز	ج
ب مد	ج ب	—	ه يه	و م	ز له	ز ن	د
ج ز	ج ل	—	و ن	ي ز	يج لح	يه ٠	ه
ج يو	ج ما	—	ز لز	يب لب	كب ب	ل ٠	و

[3] طولًا MS


المقياس
صورة المكحلة
السرطان
الاسد
السنبلة
الميزان
العقرب
القوس

III Translation

Text 1: On the construction of the astrolabe — $\mathcal{B}$:77v–81v

In the name of God, the Merciful and Compassionate.

The construction of the astrolabe

The determination of the radii from the table in which is written (*al-jadwal al-muthbat fīhi*) the distance between the centre and the altitude circles, which are located to the north and to the south of the equator on the meridian, for each single degree (of argument).

If you want (to calculate) that, divide the <half->diameter (into) 150 (parts). Then subtract from 90 the latitude for which you want to construct (the astrolabe). (In the table) take (the entry) opposite the remainder in the first column, which is the northern one, and this will be the distance of the horizon for this latitude from the centre of the astrolabe. Add to it (the entry) in the second column, which is the southern one. Then take half of the sum, and this will be the radius of the horizon for the latitude you want.

If you want the radius of another altitude circle among those (located) between the centre and the horizon, subtract from the latitude the number of the altitude circle which you want. Subtract the remainder from 90 and take (the entry) opposite it in the first column, and this will be the distance of that altitude circle from the centre of the astrolabe and towards the horizon. Keep it in mind. Then add to the latitude the number of this altitude circle. Subtract the result from 90. Take (the entry) opposite this (value) in the second column. Add it to what you kept in mind and take half of (the sum), and this will be the radius of the altitude circle which you want.

If the altitude circle is one of those (located) between the centre and the side ⟨78r⟩ of the suspensory apparatus, subtract the latitude from (the number of) the altitude circle. Subtract the remainder from 90, and take (the entry) opposite the result in the first column. [Keep it in mind.] Then add the latitude to the number of the altitude circle. Subtract the sum from 90. Take (the entry) opposite the remainder in the second column. Subtract from it that (quantity) which you kept in mind. Take half of the remainder, and this will be the radius of this altitude circle. Keep on doing this until you find that (the entry) opposite the altitude which you want is smaller than 150; when this happens, insert the circle on the plate, and you can dispense with the radii.

Table 1: ⟨78r⟩ Table for determining the altitude circles for all latitudes, in which are the (given) centres and radii between the centre of the astrolabe and the positions of the altitude circles on the meridian to north and south of the equator, which is good and tested in the best possible manner, God Exalted willing, and with Him (alone) is strength.

78v

Number	north	south	Number	north	south	Number	north	south
1	96;31	99;14	31	55;34	173;38	61	25;24	379;39
2	94;11	101;40	32	54;27	177;8	62	24;29	393;49
3	93;12	103;28	33	53;19	180;50	63	23;34	409;0
4	91;35	105;18	34	52;13	184;40	64	22;40	425;58
5	89;59	107;9	35	51;7	188;37	65	21;46	442;54
6	88;25	109;2	36	50;2	192;42	66	20;52	461;17
7	86;53	110;18	37	48;57	196;16	67	19;58	482;36
8	85;22	112;17	38	47;53	201;19	68	19;5	505;8
9	83;52	114;18	39	46;50	205;12	69	18;12	529;46
10	82;23	117;1	40	45;46	210;35	70	17;19	556;52
11	80;56	119;7	41	44;45	215;28	71	16;26	586;45
12	79;31	121;15	42	43;43	220;32	72	15;33	619;57
13	78;8	123;26	43	42;42	225;49	73	14;40	657;0
14	76;45	125;40	44	41;41	231;19	74	13;48	698;39
15	75;23	127;57	45	40;41	237;5	75	12;55	745;44
16	74;2	130;17	46	39;41	243;2	76	12;3	799;42
17	72;29	132;41	47	38;42	249;16	77	11;11	861;19
18	71;41	135;8	48	37;42	255;47	78	10;19	934;11
19	70;2	137;35	49	36;43	262;36	79	9;27	1019;43
20	68;45	140;13	50	35;44	269;45	80	8;35	1122;48
21	67;29	142;14	51	34;46	277;14	81	7;43	1247;36
22	66;14	145;34	52	33;48	285;5	82	6;51	1404;9
23	65;49	148;21	53	32;51	293;21	83	6;0	1605;21
24	63;45	151;12	54	31;57	302;5	84	5;8	1873;30
25	62;33	154;8	55	30;57	311;20	85	4;17	2248;11
26	61;21	157;40	56	30;1	321;8	86	3;26	2811;12
27	60;10	160;13	57	29;5	331;30	87	2;34	3748;7
28	59;0	163;24	58	28;9	342;28	88	1;43	5624;11
29	57;11	166;41	59	27;14	354;11	89	0;52	11252;50
30	56;42	170;4	60	26;59	366;20	90	0;0	—

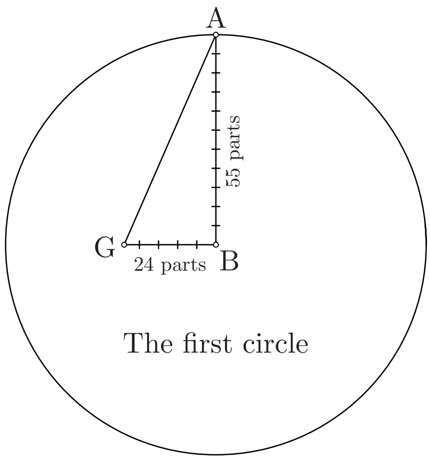
⟨78r⟩ **The stars**. If you want to determine the distance of every fixed star from the centre in terms of the parts (you) divided into one hundred and fifty, which is (the distance) between the centre of the astrolabe and the tropic of Capricorn from this table — God Exalted willing, and with Him (alone) is strength, (then consider the following).

If you want that, look how much is the declination (*buʿd min muʿaddil al-nahār*) of the star, ⟨79r⟩ whether it is northerly or southerly. What you obtain (as) is its declination, enter it in the columns of argument (of the table) and take the entry opposite to it in the first column when the declination of the star is northerly. The result will be the distance of the star from the centre (of the plate). If you also have minutes (in the argument), interpolate for them. If the star is southerly, take the entry opposite the argument in the southern column: the result will be its distance from the centre. If there are minutes (of arguments), interpolate for them, so that you get a better (result), God Exalted willing.

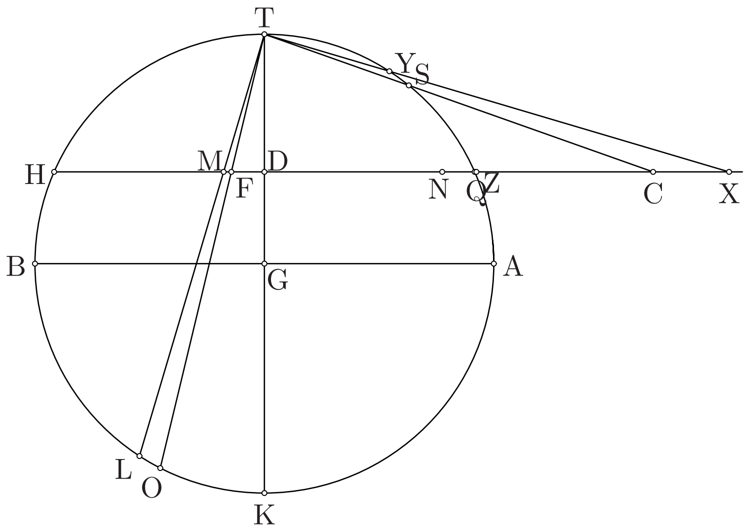
Construction of the altitude circles by geometry. Trace a circle of the same size as your plate. Divide its radius into 55 parts: this is line AB. Then from the centre draw a vertical line (*ʿamūd*) whose length is 24 of those 55 parts, perpendicular to the centre (sic! read: 'perpendicular to line AB'): this is line BG. From point G trace a line going to point A: this is GA. Take line GA and put it aside. Then make it a radius, and trace a circle around it whose radius is GA. From this circle you take the centres of the altitude circles. Then divide this circle into four quadrants. Take line BG which is 24 parts (in length) and put it (so that it goes) from point G, being the centre, to point D. Then from point D draw a line parallel to the (half-) diameter ⟨79v⟩ AG (that goes) in the direction of the letter A towards 'infinity'. This will be line ZH, intersecting the circle at Z, and then line ZD will measure the same as line AB on the first circle. Write down at the extremities of the diameter (passing through) GD the letters T, K. Then divide the quadrant AT into ninety (equal parts).

Next choose (*istakhrij*) the latitude of the plate. Count from point T the amount of the latitude of the plate which you want to make and let this be point Y. Then mark this same amount from K to H: this will be KL. From point T trace a line passing through Y (and which, i.e. arc TY, is the) latitude of the locality, until it falls on line ZH outside of the circle. It falls on point X. Trace also a line from point T to (point) L. Look where it cuts line ZH and let this be the position of M. (The distance) from point D to point M will (measure) the distance of the middle of the horizon from the east-west line, and half of line XM (will give you N) the centre of the horizon.

If you want, put the foot of the compass with this opening, namely line XN. You have put it on the line of midheaven, where it meets (the line of) the beginning of Aries and Libra. The point which you obtain is the one whose distance from the east-west line is the amount of DM. Then draw (a circle): you have thus determined the horizon. The procedure for the horizon is like that for any latitude. Add six (degrees) to the latitude if the astrolabe is sexpartite or three (degrees) if it is tripartite. Then you add six (degrees) to the (parts corresponding to) point (Y); there results arc TS. Trace a line from T to line ZH through S. ⟨80r⟩ Let this fall on C (on line ZH). Return to line (read: arc) KL and subtract six degrees from it on the side of L: this will be O. [Trace] a line [from T to O], which will cut line ZH at F. Line DF will be the distance of the second altitude circle from the east-west line. The middle of line CF is point Q.[40] Then line CQ is the distance of the centre of the second altitude circle (from point C), provided you put it on the line of midheaven. (The procedure) is for all the altitude circles, God, Almighty and Sublime, willing.



80r



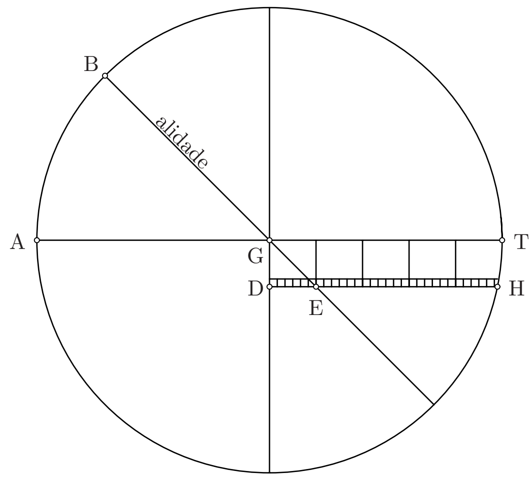
80v

The quadrant AT is divided into 90 (parts) and the computation is based on this.

[40]Note that on the diagram point Q happens to almost coincide with Z. This is entirely fortuitous! In the manuscript Q is located between D and N.

Construction of the shadow (scale) on the back of the astrolabe by geometry.⟨81r⟩ With the compass take the amount which is most appropriate, that is six parts of ninety,[41] (measured) from the centre, which is point G: let this be GD. Then trace line DH parallel to line TA which is the east-west line. Divide line GD into twelve (parts) and divide line DH in those parts (*aqsām*). Then trace another line parallel to line TG, which is as close to HD as appropriate. Divide the parts into 'fifths' (*khamasāt*),[42] as you can see on the figure along the line next to line HD. Write in alphanumerical notation on them along the line next to TG as you can see (on the figure), and begin by writing 'w' [= 6] which is next to the centre of the plate. Whenever you take the altitude with the alidade you get a shadow in (terms) of the parts of the vertical (line) whose (length) is (assumed to be) twelve, i.e., (line) GD.

Example thereof. If the altitude is the arc AB, line DH is parallel to the line of the horizon, which is line TA, and the vertical gnomon is line GD, (then) the shadow of line GD will be (the line) DE. If the altitude, being arc AB, is the half of ninety, that is forty-five, then DE will be equal to GD. And if you divided GD, which is the gnomon, (into) twelve (parts), and you divided DH in terms of those parts, you will (also) get (a result) in terms of those parts. You will then get the shadow of one hour as sixty-odd parts, each twelve thereof being equal to line GD, which is the gnomon. Know this — there is no strength but with God! This is the figure (relative to) that, (where) each single one of these parts (means) two parts, because the length of each (fifth) division is like line GD, and each box (on the scale) represents twelve (units of shadow, i.e., digits).



[41]See the commentary.

[42]Here the word *khamasāt* should be taken in a generic sense, for the subdivisions are at every six divisions.

Text 2: On the use of the astrolabe — $\mathcal{B}$:81v–91v

[1] **Muḥammad ibn Mūsā al-Khwārizmī said**: ⟨81v⟩ The first thing a person who wants to use the astrolabe needs is **to take the altitude**. If you want to take the altitude turn the astrolabe (so that you can see) its back, then suspend it with your right (hand) ⟨82r⟩ and stand with the sun in line with your left shoulder. Place the 90 lines (of the altitude scale) on the back of the astrolabe toward the centre of the sun (*ʿayn al-shams*). Then keep on raising the alidade until you see the sun entering both holes (of the sights). Then look where the pointer on the alidade — which is its sharp end — falls on the 90 parts which are on (the scale of) the back, and this will be the altitude of the sun at that time, so keep it in mind.

[2a] **If you want to determine the ascendant and how many hours of daylight and fractions thereof have elapsed**, take the altitude as I described to you, and likewise (for) the position of the sun in its sign and its degree that you have determined. Then place (the mark corresponding to) the degree of the sun in its sign (*darajat al-shams fī burjihā*, i.e., the solar longitude) on the appropriate altitude circle (*ʿalā mithl dhālika al-irtifāʿ min al-muqanṭarāt*), on the east side if your measurement is before noon, and on the west side if your measurement is after noon. Then look which sign and how many degrees thereof is cut by the first of the altitude circles on the east side (i.e., the horizon), then the degrees of that zodiacal sign will be the ascendant. Then look at how many hours the degree opposite the sun (*naẓīr darajat al-shams*) falls, beginning with the number of the hours on the west side, and this will be (the amount) elapsed of the hours of daylight, and the fractions thereof if there are any. Keep in mind the whole hours.

[2b] **If you want to determine the fractions ⟨82v⟩ to be added to the whole hours**, look where the index (*murī al-ajzāʾ*) at the beginning of Capricorn falls on the degree(-scale) of the limbus. Then, look at the degree opposite the sun until you place it on the hour which is completed. Next, look at how much the index has decreased from the place where it was. These degrees are the excess over the whole hours, and this is to be put in proportion to the parts of the hours of daylight for that day.

[2c] If you want to determine the parts of the hours of daylight, bring back the degree opposite the sun to the other hour from this second position. Then look at how much the index has decreased from its second position. These will be the parts of the hours, so keep them in mind. Put this fraction of an hour in proportion to it, and this will be the hours of daylight elapsed and the parts thereof. Then look which sign and which degree is cut by the line of midheaven through the suspensory apparatus (i.e., the vertical axis), (and) this will be the degree of midheaven and the (degree of) the 'pivot of the earth' (*watad al-arḍ*) is the same as this.

[2d] **Example for this**. We measured the sun in Baghdād (*madīnat al-salām*) and we found the altitude to be twenty four degrees in the first (half) of the day.

The sun is the 12th degree of Scorpio. We place the degree of the sun on the twenty fourth altitude circle on the east side because the altitude was (measured) in the first (half) of the day. We find the eastern altitude circle (that is, the eastern horizon) to cut ⟨83r⟩ the signs (on the ecliptic scale) at nine degrees of Sagittarius. Hence we know that the ascendant is nine degrees of Sagittarius. And we find the midheaven 22 degrees of Virgo. The degree opposite the sun is 12 (degrees) of Taurus. We find that it has fallen on a part of the third hour. We look at the index and find it at two hundred and sixty three degrees on the limbus of the astrolabe — we keep it in mind.

Then we move back the degree opposite the sun and place it on the (curve for) two whole hours. We find that the index has moved back from its (original) position by six degrees. So we know that the six degrees are the increase over the two hours. These are to be put in proportion to the degrees (corresponding to) the hours of daylight. We find that the index has moved to 257 (degrees) of the limbus — we keep it in mind. Then we want to know the parts (corresponding to) the hours of daylight, so we move back the degree opposite the sun to three whole hours, then we look at the index and find that it falls at 270. So we take the excess between that and 257 and find it to be 13 degrees. Thus we know that two (whole) hours of the day and six out of 13 parts of an hour have elapsed.

[3] If you want to determine the ascendant and the hours at night by measuring (the altitude) of the fixed stars,[43] suspend the astrolabe with your right (hand), face the star which you want to measure with the two holes of the alidade. Then look through both holes of the alidade until you see the star ⟨83v⟩ with one of your eyes through both holes. Then look at which mark (of graduation) the index — (namely) the pointer of the alidade — falls, and this will be the altitude of the star you have measured. Then turn the astrolabe (so that you can see its front) and place the sharp end of the star (pointer) on the same altitude (circle) on the east (side), if the star is not (yet) decreasing from midheaven, or on the same altitude on the west side, <if the star is decreasing from midheaven>. Look at which sign and which degree (thereof) is cut by the eastern horizon, and this will be the ascendant. (Then look at which degree) is cut by the line of midheaven, and this will be the degree of midheaven. Then look on which hour the degree of the sun falls: this is the number of hours of night elapsed. Operate with the fractions of the hours with the degree of the sun at night — just as you operate with the degree opposite the sun by day.

[4a] If you want to check the correctness of the astrolabe against its defects, observe (*qis*) the sun, determine the ascendant and the hours of daylight elapsed, according to what we described at the beginning of the book. When you determined this with the astrolabe, then determine it by calculation with a *zīj*. If it

[43]Text: 'and the measurement is by the fixed stars'.

agrees with the result (obtained) with the astrolabe, the astrolabe is accurate.

[4b] **Example for this**. We observed the sun: it is in the fifteenth degree of Taurus. We found the altitude to be 44 degrees. We determined the hours of daylight elapsed by calculation with a *zīj*. It was three hours ⟨84r⟩ and a sixth — that is, fifty three degrees and fifteen minutes of the sphere had revolved. <...>. We bring that in (the column of) the ascension for Baghdād (*madīnat al-salām*) listed in the *zīj*. We find the ecliptic degree opposite to it (as) 24 degrees and two minutes of Pisces, and this will be the degree of midheaven. If you find the same result on the astrolabe, then it is accurate.

[5a] **If you want to determine the arc of daylight for every day**, place the degree of the sun on the eastern horizon (*muqantarat al-mashriq*). Then, look where the index falls and put a mark on it. Turn (the rete) until the degree of the sun falls on the western horizon. Next, look at where the index falls. Count what is between the first and second positions of the pointer (on the eastern and western horizons) in terms of the scale of the limbus (*min al-ʿadad alladhī ʿalā al-ḥujra*): this will be the arc of daylight.

[5b] **If you want to determine the amount of the nocturnal arc**, subtract the arc of daylight from 360. The result will be the nocturnal arc. If you want to determine the nocturnal arc by (the use of) the astrolabe, operate with the degree opposite the sun.

[5c] **If you want to determine the hours of daylight**, divide the arc of daylight by 15. This will be the hours of this day. Subtract the hours of daylight from 24. The remainder will be the nocturnal hours.

[6] **If you want to determine the right ascensions with the astrolabe**, place the first line (i.e., subdivision) of Capricorn ⟨84v⟩ on the line of midheaven. Then look how many degrees around the limbus are cut by the pointer, and this will be (the point) with which it rises. (Operate) in the same manner for all (other) signs.

[7] **If you want to determine the ascensions of every locality**, (that is, the oblique ascensions), place the (plate for the) latitude of the locality on top of the (other) plates. Then consider (*iʿtariḍ*) whichever sign you want and place its beginning on the eastern horizon. Then rotate it until it comes to its end. Look at how many (degrees) are cut by the index: this will be (the point) with which it rises. Operate in the same manner for all (other) signs.

[8] **If you want to determine the degree of the sun**, take its maximum altitude for this day. Then determine in which season of the year you are. Rotate the (corresponding) signs of the season in which you are on the line of midheaven. The (degree) among them that falls upon the altitude you have found will be the degree of the sun.

[9a] **If you want to determine the degree of the moon or of the five planets**, measure the maximal altitude (i.e., the meridian altitude) of the moon or

of whichever of the five planets you want. Then measure the altitude of one of the fixed stars at the same time as you measured the (meridian) altitude of the moon or of whichever of the five planets you want. Determine the ascendant from the (altitude of the) fixed star, as I described to you at the beginning of the book.[44] Then look which sign and which degree (is cut) by the line of midheaven: this is the degree of the (moon or) planet.

[9b] If you want to determine the latitude of the planet, look at how much is the altitude of the planet which you measured, and determine its position. If it is more than the altitude of its degree (on the ecliptic scale) ⟨85r⟩ in which you have found it (i.e., the planet),[45] take the difference between both: this will be its northern latitude. If the altitude of the planet is less than the altitude of its degree, the difference between both will be its southern latitude.

[10] If you want to determine the declination of whichever degree you like, place the degree you want on the line of midheaven. Then look at how many (degrees) of altitude are cut by it, and keep it in mind. Next, look at the circle on the plate on which rotate the beginnings of Aries and Libra, (and look at) how many (degrees) of altitude it meets the line of midheaven. Take the difference between both, and this will be the declination of the degree — God willing. If the altitude of the degree is more than the altitude of the beginning of Aries, the declination is northerly, if it is less, it southerly.

[11a] If you want to determine the positions of the fixed stars on the astrolabe, place the sharp extremity of the star (pointer) on the line of midheaven. Then look at which sign and which degree (thereof on the ecliptic belt) coincides with the line of midheaven: this will be the position of the star with respect to the longitude.[46] Know it, God willing.

[11b] If you want to determine the latitude of the fixed stars, look at the altitude of the degree with which the star culminates (*yamurru*) on the line of midheaven, and keep it in mind. <Look also at how many degrees of altitude the star pointer cuts on the line of midheaven.> Then take the difference between both, and this will be the latitude of the star. If the altitude ⟨85v⟩ of the extremity of the star (pointer) is larger than the altitude of its degree (of mediation), it is northerly. If it is less, it is southerly.

[12a] If you want to determine with which degree the star rises, place its sharp extremity (i.e., of the star pointer) on the eastern horizon. Then look at which

[44] The ascendant as such is not required here. The implied meaning is that the appropriate star pointer should be brought over the altitude circle corresponding to the observed altitude of the star, exactly as in §3, whose purpose was, among other things, to find the ascendant.

[45] In other words, if the measured meridian altitude is more than the meridian altitude of the degree of the ecliptic corresponding to the longitude of the planet.

[46] This is actually the mediation of the star.

sign and which degree (thereof) coincides with the eastern horizon: the star will rise together with this degree.

[12b] If you want to know with which degree (the star) sets, place the extremity of the star (pointer) on the western horizon. Then look at which sign and which degree (thereof) coincides with the western horizon: it will set with it (lit.: in it).

[12c] If you want to determine which degree (of the ecliptic) makes its daily rotation with the star (*maʿa ayyi daraja yajrī al-kawkab), and how much its meridian altitude is*, place its sharp extremity (i.e., of the star pointer) on the line of midheaven. What coincides with it will be the meridian altitude of the star, that is, its maximum altitude for this locality. Then rotate the ecliptic belt: the degree corresponding to this altitude on the line of midheaven will be the one on whose path the star makes its daily rotation.

[13] If you want to determine the declination of the star, look on (the line of) midheaven at the altitude of the extremity of the star (pointer) and at the altitude of the tropic of Aries. Take the difference between both: this will be its declination from the equator. If the extremity of the star (pointer) is inside the tropic of Aries, on (the side) towards the pole, its distance is northerly. If it is outside, on (the side) towards the limbus, its distance is southerly.

[14] If you want to determine the arcs of any star you like, place the extremity of the star (pointer) on the eastern horizon. ⟨86r⟩ Then look where the index falls, and keep it in mind. Then rotate the extremity of the star (pointer) until it is placed on the western horizon. Then look where the index falls and count (the divisions on the outer scale) from the first position to the second one, along the day-circle of the star: this will be its arc of visibility (*qaws nahārihi*).

[15a] If you want to determine the shadow from the altitude and its construction, that is, how it is made, place the index which is on the alidade on the forty fifth (division) of the altitude (scale). Then look where, on the circle of the back of the astrolabe, falls the extremity of the index which is opposite (that) altitude. Put a mark on it. Then from this (point) draw a line perpendicular to the line opposite the suspensory apparatus of the astrolabe, which is the (vertical) diameter of the circle, and another line perpendicular to the line which cuts the east-west line. Then divide each of these two lines into 12 equal parts. This is its construction.

[15b] If you want to know its use so that you can determine the shadow, measure the (altitude of the) sun whenever you want. Then look at which of the two lines opposite the altitude (scale) the index will fall upon, and on how many of its divisions. If the altitude is less than 45 (degrees), count from the (upper) right angle to the index: this will be the vertical shadow (*quṭr al-ẓill*[47]). If the altitude is

[47]See the commentary.

more than 45 (degrees), count from the (lower) right angle (to the index): this will be the (horizontal) shadow.

[16] If you want to determine the latitude of the locality, measure (the altitude of) the sun at midday as high as possible and keep it in mind. ⟨86v⟩ Then turn the astrolabe (so that you can see its front) and place the degree of the sun on the line of midheaven. If the value of the altitude you obtained coincides (with it), then you are in this climate whose latitude is the same as the latitude of this plate for which you have measured (the solar altitude). If the (measured) altitude is different from the (meridian) altitude of the degree of the sun (as found on the plate), take what is between the altitude of the degree of the sun and the altitude of the beginning of Aries[48] on the plate, and keep it in mind. If it is on the northern side, subtract what you have kept in mind as the difference between both altitudes from the altitude you obtained by measurement: this will be the altitude of (the beginning of) Aries in your climate. If the sun is on the southern (side), add what you have kept in mind to the measured altitude, and this will be the altitude of (the beginning of) Aries for your locality. Subtract the result of the addition or subtraction from ninety. The remainder will be the latitude of the locality.

[17] If you want to determine the altitude from the ascendant, look at the degree of the ascendant and put it on the eastern horizon. Then look at how many (degrees) of the altitude circles the degree of the sun falls: this will be the altitude of (the sun at) this hour. Then look (whether) it is from the east or from the west. Know this, God willing.

[18] If you want to determine (the amount) of the hours of daylight elapsed from the ascendant, place the degree of the ascendant on the eastern horizon. Then look, if it is by day, ⟨87r⟩ at how many hours and fractions thereof the degree opposite the sun falls, according to what I have shown you: this will be (the amount) of the hours of daylight elapsed. If it is at night, look at how many (hours and fractions thereof) the degree of the sun falls: this will be (the amount) of the hours of night elapsed .

[19] If you want to determine the altitude of the sun from the hours, place the degree opposite the sun on (the curve for) whichever hour you want. Then look at how many (degrees) of altitude the degree of the sun falls <on> the altitude circles on the east or west side: this will be the altitude.

[20] If you want (to determine) the altitude of some stars from the ascendant at night, (namely the stars which are) above the earth (i.e., above the horizon), place the degree of the ascendant on the eastern horizon, if you want (to find) this from the ascendant. If you want (to find it) from the hours, place the degree of the sun on (the curve for) whichever hour you want. Then look at which (degree) of the altitude on the east and the west corresponds to the visible

[48] I.e., the colatitude of the locality.

star: this will be the altitude of this star <at> this hour.

[21] If you want to determine from the altitude of a star whether it is night or day. The altitude of the star is given to you as a certain number (*fa-qīla laka irtifāʿ al-kawkab ʿadad maʿlūm*), towards the east side or the west (side), and you want to know (whether it is) by night or by day: place the extremity of the star (pointer) on the corresponding altitude (circle) towards the direction in which it, I mean the star, is. Then look at the degree of the sun: if it falls on some part of the altitude circles, it is (during the) day. If it falls on (something) different from this, it is (during the) night.

[22a] ⟨87v⟩ **If you want to convert the equal hours into seasonal (hours) or the seasonal (hours) into equal (hours)**, place the degree opposite the sun on (the curve for) whichever hour you want. Then look where the index falls, and keep it in mind. Then rotate the degree opposite the sun until it falls on the western horizon. Next, look where the index falls. Take the quantity between both (positions of the index) on the limbus: this will be the amount of revolution of the sphere since the rising of the sun until this hour. Divide it by 15, then this will be the equal hours (elapsed since sunrise).

[22b] If you want to determine the seasonal hours from the equal hours, take the equal hours and multiply them by 15. Keep (the result) in mind. Then place the degree opposite the sun on the western horizon. Look where the index falls, and keep it in mind. Then rotate the index in the sense of the rotation of the sphere (*ʿalā madār al-falak*) until it has decreased from its position by the amount resulting from your multiplication of the hours by 15. Next, look at how many hours the degree opposite the sun falls: these will be the seasonal hours. If there are fractions, do this operation with the degree of the sun just as you did it with the degree opposite the sun.

[23] If you want to determine the twelve houses when you know the ascendant and the 'cardinal points' (*al-awtād*), take the degree opposite the ascendant and place it ⟨88r⟩ on the (curve for) two hours on the west side. Then look which (part) of the signs is cut by the line of midheaven: this is the (beginning of the) 'House of Hope'. Then place the degree opposite the ascendant on the (curve for) four hours. Then look which part (*shayʾ*) of the signs is cut by the line of midheaven: this is the 'House of Enemies'. Then place the degree opposite the ascendant on the (curve for) six hours. Then look which (degree) is cut by the line of midheaven: this is the ascendant. If it coincides with the ascendant, then you are right. If it is different, then you are at fault: fix up your work! Next, place the ascendant on the (curve for) ten hours which is towards the west; (or), if you want, on (the curve for) two hours which is towards the east. Then look which part sign and degree (thereof) cut the line of midheaven: this is the 'House of Travel'. Place the ascendant on the (curve for) eight hours which is towards the west. Then look which (part) of the signs is cut by the line of midheaven: <this is> the eighth house. The 'House of

Property' is opposite the eighth house. The 'House of Brothers' is opposite the 'House of Travel'. The 'House of Fathers' is opposite the line of midheaven. The 'House of Children' is opposite the 'House of Hope'. The 'House of Illness' is opposite the 'House of Enemies'. The seventh house is opposite the ascendant. If you wish to determine (the houses) with the astrolabe, (consider the following): when you have determined one of these houses on the line of midheaven, that which cuts the 'pivot' of the earth will be the opposite of this house — God Exalted willing.

[24] [49] **The determination of the projection of the rays (*maṭraḥ al-shuʿāʿ*) with the astrolabe**. Place the part of whichever degree you want on the horizon (*awwal muqanṭara*), and put a mark at the beginning of Capricorn. ⟨88v⟩ Then add 60 to the (degree of the outer scale corresponding to that) mark, and increase (the position of) the beginning of Capricorn to which you have added (60). The ascendant in degrees (*ajzāʾ*) on the eastern horizon will be (the ray of) the sextile light (*nūr al-tasdīs*). In the same way (you can find) the quadrature (*al-tarbīʿ*), and the trine (*al-tathlīth*). The opposite (*al-muqābila*) of the degree of the ascendant is the degree of the descendant (*darajat al-ghārib*).

[25] The year-transfer of the nativities (*taḥwīl sinī al-mawālīd*) with the astrolabe. If you want to know this, then consider the (number) of whole years of nativities elapsed. Multiply it by 93 degrees and two minutes. Subtract from the sum one rotation (that is, 360 degrees) if there is (one) and keep the remainder in mind. Then rotate the rete until the ascendant of the nativity coincides <with the eastern horizon>. Then determine the position opposite the index on the lines of the limbus. Next, add what you kept in mind to the (value corresponding to the) position of the pointer. Bring the index to the position vis-à-vis the number reached (as a result of the addition). Then what is on the the eastern line will be the ascendant of the year of nativity.

[26a] If you want to determine the ascendant of the year with the astrolabe, consider the ascendant of the year elapsed and place this degree on the eastern horizon. Look at what it will be and add to it 93: this will be the ascendant — God Exalted and Sublime willing.

[26b] If you want to determine the ascendant of the first season (of the year) (*al-rubʿ al-awwal*), place the ascendant of the year on the eastern horizon. Then look at which number of the degrees on the limbus the index falls. Add to this 49. Then rotate the index to the number which you have added. ⟨89r⟩ Then look at the eastern horizon. Which sign and which degree it cuts (this) is the ascendant of the first season. Add to the first season its increase. This is the second season. In the same way you do with whichever season you want — God Exalted willing.

[26c] ⟨89v:7-11⟩ **I found in another copy**: If you want to know the ascendant

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[49] This section and the following ones have their heading centered on individual lines, which *may* indicate that they are additions taken from other sources. Cf. §26c.

of the year add to the ascendant of the year elapsed 93 degrees and 15 minutes. Between the ascendant of the year and the first season are 49 degrees and two thirds of a minute. Between the ascendant of the year and the second season are 173;50 (degrees). Between the ascendant of the year and the third season are 171;45[50] (degrees). Know this — God Exalted willing.

[27] ⟨89r (cont.)⟩ **To determine whether the city in which (you are) is to the south or to the north (with respect to another one)**. Consider (the city with) the greater altitude (of the sun): (it) will be nearer to the south. And the (city with the) smaller altitude (of the sun) will be nearer to the north. *Explanation of this*: If you measured (the altitude of) the sun at Rayy when it enters the first degree of Aries, you found it 53 degrees. Then you measured it in Kufa and you found 58 (degrees) on the same day. Between the two (altitudes) there are five degrees, and the (city with the) greater altitude is the one nearer to the south. Measure in the same way (in other cities) — God Exalted willing, and with Him (alone) is strength.

[28a] **The determination of daybreak and nightfall**. Place the degree (*juzʾ*) of the sun on 18 (degrees) of the altitude circles on the west side. Then look at how many hours the degree <opposite> the sun falls: this will be the hour at which the day breaks. Know this, God willing.

[28b] **Nightfall**: If you want to determine when the night falls, place the degree opposite the sun on 18 (degrees) of altitude on the east side. Then look at how many hours the degree of the sun falls: this will be the hour at which the night falls.

[28c] ⟨89v:1–6⟩ **The determination of the time of midday prayer (*al-ẓuhr*) and afternoon prayer (*al-ʿaṣr*)**. If you want (to know) this from the altitude, observe the sun until it is on the line of midheaven (and measure its altitude). Then subtract seven degrees from the altitude: this will be (the altitude at) the midday prayer. As for the afternoon prayer, take the meridian altitude of your day, and subtract 90 from it. Take one tenth of the remainder and add this tenth to one half of the meridian altitude of your day. The result will be the altitude at the time of the afternoon prayer — God willing.

[28d] ⟨90r:11–17⟩ **The <end of the> time of midday prayer**. If you want to determine the end of the time of midday prayer, place the degree of the sun on 14 (degrees) of the azimuth (circles) on the west side. Then look at how many (degrees) of the altitude circles it falls, and this will be the altitude at the end of the time of the midday prayer, on the west side.

[28e] **If you want (to determine) the end of the time of afternoon prayer**, always subtract the meridian altitude from 90. Take one tenth of the remainder, and add it to the meridian altitude. The result will be the altitude (of the sun) at the end of the time of the afternoon prayer. Know this!

[29] ⟨89v:12–17⟩ **The determination of the azimuth with the astrolabe**.

[50] Read 271;45.

Take the altitude, and put (the degree corresponding to) the degree (*juzʾ*) of the sun on (altitude circle) for the value of the altitude which you obtained, either on the eastern or the western side. When you have done this, look at which of the curves engraved for the azimuth the degree of the sun coincides with: this will be the azimuth at the time when you have made the measurement. If the number which you obtained runs from the east (*mashriq al-istiwāʾ*) towards (the line) 'underneath ⟨90r:1–11⟩ the earth' (that is, the northerly part of the meridian line), the azimuth will be between the east and the north. If (the number) which you obtained for the azimuth runs from the east towards the (line of) midheaven, the azimuth will be between the east and the south. If the azimuth which you obtained is from the (line of) midheaven towards the west point, the azimuth will be between the south and the west. If the azimuth is from the west towards the line 'underneath the earth', the azimuth will be between the west and the north.

Let your use of the azimuth (be as follows): If you want to use it and to determine with it the meridian line by this method (consider the following): The eastern line[51] (is found by means of) the azimuth lines as being the line that separates them between the two six-degree marks (*al-khaṭṭ al-fāṣil lahā fīmā bayna al-wāwayn*) on the eastern (side). And the western line, on the western (side), is the line that separates <them> also between the two six-degree marks.

[30a] ⟨90v⟩ **The determination of the time of moonrise**. If you want this, determine the longitudes (*juzʾ*) of the sun and of the moon. If there are less than 180 degrees between the moon and the sun divide it (i.e., the ascensional difference) by the duration of daylight in hours. The result in hours will be the hours of the day that have elapsed until the time of its rising (i.e., of the moon). If there are between the sun and (the moon) more than one hundred and eighty (degrees), multiply the duration of daylight in hours by 12 and subtract it from the distance between both. Divide the remainder by the (duration) of night in hours: this will be the hours of night elapsed until its rising. What is used as a 'distance' for the division is the (quantity) between the sun and the moon considered as ascensional degrees. (To find) the longitudes of the sun and of the moon (consider the following): If (the difference in ascensions) between the moon and the sun is less than the half-arc of daylight and if it is nearer to the rising (of the sun), find the true positions (from the mean positions — *qawwimhumā*) at sunrise. If it is nearer to midday, find the true positions at midday. If it is nearer to sunset find the true positions at sunset. And do the same at night if it is more than the arc of daylight and less than <the arc of daylight and> the half-arc of night. If it is nearer to the beginning of the night, find the true positions at midnight. If it is nearer to sunrise (find the true positions) for the following day. This is an approximate method. If you want to determine it more exactly, find the degrees of the sun and of the moon at the time ⟨91r⟩ corresponding

[51] I.e., the eastern half of the prime vertical.

to these hours which you derived, at night or by day. Then operate with it just as for the first operation.

[30b] If you want to know how long it stays (visible): If the night has started when (the moon) rises, subtract the distance between it (i.e., the ascensional difference sun-moon) and the arc of daylight <from the arc of day of the moon>. Divide the remainder by the duration of each hour of night (*azmān sāʿāt al-layl*). The result will be the hours of its visibility (*sāʿāt makthihi*). And it is rising. Know this — God Exalted willing.

[30c] The determination of the ascendant by means of the moon with the astrolabe. Take the altitude of the moon and determine whether it is towards the east or the west. Calculate the longitude of the moon at this hour and its latitude. If the latitude of the moon is northerly, subtract from the altitude of the moon the amount of the latitude of the moon. If the latitude of the moon is southerly, add to the altitude of the moon the amount of latitude of the moon. The altitude of the moon you obtain after this <you keep in mind>. Place the degree of the moon in its sign on the value of this altitude on the east side, if the moon whose altitude you have taken is in the east. If it is in the west, (put it) on the west side, just as you did for the sun. Then the degree of the sign which is on the eastern horizon (*khaṭṭ al-mashriq*) will be the ascendant. Know that if the moon has passed the 'Head (of the Dragon)'[52] and has not yet reached the 'Tail (of the Dragon)',[53] then its latitude is northerly. If the moon has passed the 'Tail' and has not yet reached the 'Head', then its latitude is southerly. ⟨91v⟩ *Al-yamanī* (?) is the south and *al-jawfī* (?) is the north. Know this – God Allmighty willing.

[31] If you want to determine the 'meridian differences' (*intiṣāf al-nahār*) in the cities, take the (altitude of the) sun (through) both holes of the alidade at midday in one of the two cities. Take it in the other (city) on that same day. Then subtract the smaller (altitude) one from the greater one. Every 15 (degrees) of the difference you obtain represents one equal hour. The greater of both will be nearer to the East.

[31b] Example for this: The longitude of Baghdad is 70 (degrees) and the longitude of Damascus is 60 (degrees). There results two thirds of an hour.

Text 3: On a compass for finding the prayer-times — $\mathcal{B}$: 91v–92r

The use of a compass with which the prayer times are determined and the shadow measured. If you want to do what we have mentioned, take — sublime is the name of God! — a compass, if you want of ivory or if you want of something similar to whichever [...] you want. Make it perfectly quadrangular,

[52] That is, the ascending node.

[53] That is, the descending node.

smooth and extremely straight (*rabbiʿhu tarbīʿan mustawiyan muhandasan shadīd al-istiwāʾ*) from the grip to the two pins (lit. 'pens', *qalamān*). Make for that the two pins of iron. Divide the breadth of the compass on the west side into four parts, and the length into four equal parts. Write on it the signs from Aries to Virgo in the (correct) order. Take (*ukhrij*) its calculation from the table. Write opposite every sign which is for that by the calculation just as you see it represented. Then divide also the east side of the compass in the same way. Write on it the signs from Libra ⟨92r⟩ to Pisces. Write opposite every sign its calculation just as you have done for the first (time). Then divide on the north side — that is, the front of the compass — and the south respectively into twelve parts. Write on it the number. Begin the writing of the number on the side of the two pins of the compass. If you have finished this totally, fasten the compass with nails of iron. At the end of the nails are small metallic disks (*fils*) just as you see it represented — know this!

Table 2: <Table of the beginning of midday prayer, the beginning of the afternoon prayer and its end, for every six degrees of solar longitude and> for latitude 33° ($\mathcal{B}$:94r)

North — West

Zod. signs	Beg. ẓuhr	Beg. ʿaṣr	End. ʿaṣr	Number
Cnc / Gem	2	13	25	0
	2	13	25	6
	2	14	25	12
	2	14	25	18
	2	14	25	24
	2	14	25	30
Leo / Tau	2	14	26	6
	3	15	27	12
	3	16	28	18
	4	16	28	24
	4	17	28	30
Vir / Ari	5	17	29	6
	6	17	29	12
	6	18	31	18
	7	19	31	24
	8	20	32	30

South — East

Zod. signs	Beg. ẓuhr	Beg. ʿaṣr	End. ʿaṣr	Number
Lib / Psc				
	8	20	32	6
	9	21	34	12
	10	22	34	18
	11	23	36	24
	12	24	36	30
Sco / Aqr	12	25	36	6
	13	25	38	12
	14	26	39	18
	16	28	39	24
	16	28	41	30
Sag / Cap	17	29	41	6
	17	29	42	12
	18	31	43	18
	18	31	44	24
	18	31	44	30

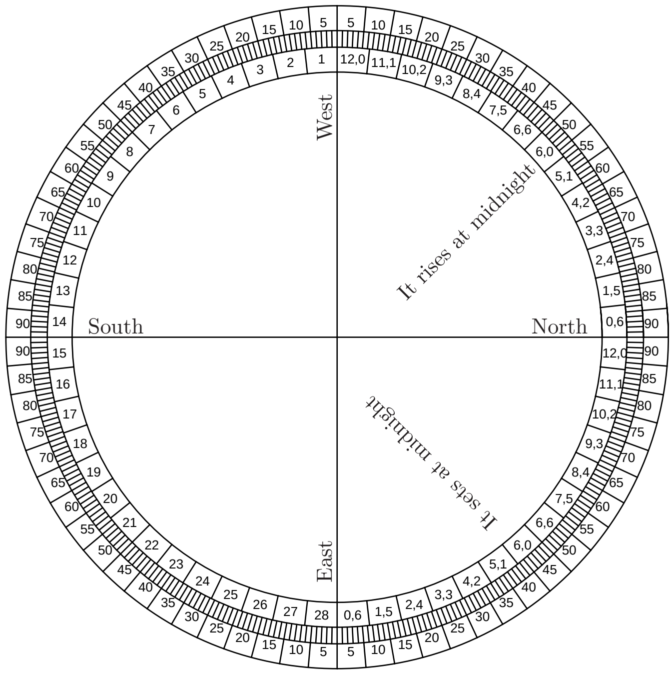
[*Marginal note*:] If you want to determine the midday shadow of your day, subtract the half arc of daylight from the ascension (of the arc) between the beginning of Cancer and the end of Sagittarius. Divide the remainder by 15 and the result will be the midday shadow of your day, God Exalted willing.[54]

[54] On this procedure see King (2004: 235). A rapid investigation of this method demonstrates that it does not make any sense whatsoever (it yields shadow lengths varying from 6;17 to 10;6 digits, instead of 2;0 to 18;10).

The description of the use of this compass. If you want to determine the prayer times with this compass for which I have described the making, put (it) in a level place on the ground. Join the compass until the two pens get together. Then plant the two pens of the compass on the ground until (the two pens) sink into (the ground). Then put a mark on the end of the shadow which comes out by the compass at every time you are. Then pull out the compass from its place and survey by it the shadow in fingers divided on the compass — there are twelve fingers. The resulting sum of fingers, and keep it in mind. Then look at the shadow of the times which are on the compass opposite the sign in which the sun is. If the shadow which you kept in mind corresponds to the shadow on the compass, this is the time of this prayer. If it is less or more observe it a little bit until your shadow for this prayer becomes complete according to that on the compass — God willing.

Text 4: On a 'moon plate' — $\mathcal{B}$: 92r-93r

The use of the plate with which the altitude is measured and the moonrise is determined ⟨92v⟩ **for every night, and when it sets and the duration of its staying**. If you want to do what I have described, take — by the blessing of God — a firm and thick plate of the size you want. Draw on it two lines cutting each other at the centre at right angles. Write on it its four (cardinal) directions: East, West, South, and North. Then trace three circles on the southern side, the first one being the circle of the five (degree arguments) (*dāʾirat al-khamasāt*). Divide it from the East to the West into thirty six parts. Write on it 'circle of the five (degree arguments)'. Begin your labeling of (the circle) of the five (degree arguments) from the east and the west simultaneously until you reach (from both sides) the ninety-degree division on the (line of) midheaven. The second circle is the altitude circle. Divide it into eighty-eight parts. The third circle is the circle of the duration of the nights (*ʿadad al-layālī*). Divide it into twenty-eight parts. Label it from 1 to 28, beginning your writing from the west to the east as you can see it written on the plate. When you have finished (the labeling) on the southern side, trace a wide circle on the northern side, and divide it into 28 parts. Write on it the (result of the) calculation according to what is in the table. Begin your labeling from the east to the west as you can see it written on the plate. Then make an alidade for it, and mount it upon it in a smoothly fitted way. Use it — God Exalted willing, and by Him is strength. ⟨93r⟩



Text 5: On the species of astrolabes — $\mathcal{B}$: 96r

⟨96r⟩ **The Chapter of the knowledge of the cause by which the astrolabe is called 'complete', 'bipartite', 'tripartite', 'quinquepartite', 'sexpartite' or otherwise**. As for the markings which do not differ on any astrolabes, these are the great circles, that is, the day-circles of Cancer, Aries and Capricorn, the meridian line and the East-West line. All these markings are indeed found on all astrolabes (and) do not differ at all. But (those which) differ are the altitude circles, because there is 90 (of them) on the complete (astrolabe). On the bipartite (astrolabe) there are 45. On the tripartite there are 30, since for every three degrees (of altitude) there is one circle. That which is called quinquepartite has between any pair of (altitude) circles five degrees. If there are 15 (altitude circles) it is called sexpartite. If there are 9 (altitude circles) it is called decempartite, because the astrolabe is (called) after the (quantity) between two circles, which is ten (degrees). According to this number the zodiacal signs are (likewise) divided.

Text 6: On projecting the rays with the astrolabe — $\mathcal{B}$: 96r–96v

Projecting the rays with the astrolabe. Consider the planet for which you want to project the rays. Take its degree and place it (i.e., the corresponding point of the ecliptic) on the horizon. If you want (to) throw its rays to the left sextile, put a mark on the beginning of Capricorn. Then decrease it from its place by 60 degrees. ⟨96v⟩ Then look at which sign and which degree corresponds to the horizon. This is the place of its left sextile. If you want its right sextile, rotate the beginning of Capricorn by sixty (degrees) towards the opposite of its position: what corresponds to the eastern horizon will be the position of its right (sextile) ray. If you want the trine, add one hundred and twenty. (If you want) the quadrature, (add) 90. You should operate with the right and the left like (you have done) the first (time) — God Exalted willing.

Text 7: Ptolemy's division of five terrestrial zones — $\mathcal{B}$: 96v

The division of Ptolemy: the five (terrestrial) zones (*al-ṭarāʾiq al-khamsa*). The first zone is near the north (pole): 36 degrees and 9 minutes. The second (zone) is 30°. The third (zone) where night and day are equal is 23[55] degrees and 51 minutes north (of the equator). It is the same towards the south. The fourth (zone) is 30°. The fifth (zone) which [. . . . . .] is not seen in the south:[56] 36 (degrees) and 9 minutes. The sum of that is 180 degrees.

Text 8: On the sine quadrant — $\mathcal{B}$: 96v–97v

The construction of a quadrant with which the sine, the declination and the hours of daylight that have elapsed can be determined.

If you want to make this quadrant, take – by God's blessing and help – a quadrant of [. . .] made at right angles, coming out of the circle of the graduated plate (*dāʾirat ṣafīḥat al-qisma*). Then divide it into ninety (equal) parts. Divide (the line going) from the centre (of the quadrant) to the extremity of the ninety parts ⟨97r⟩ into 150 parts, each part equal. This is the (scale of the) sine. Then suspend there (*sc.*, at the centre) a thread with a plummet. Then make on (the scale of) the sine a (graduation mark for the) sine of every degree, following what is in the table prepared (for that purpose). (This) can be determined correctly from the table consigned (*muwaqqaʿ*) in the sine table. In order to know this you must take the sine of (every) five (degrees) of altitude. Look at how many units of the sine this is. Draw a line (corresponding to this) inside the quadrant on the plate as you can see it represented. Know this — God Exalted willing!

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[55]Text has 47. See the commentary.

[56]The probable meaning is that under northern latitudes, the stars whose declinations correspond to the fifth zone are not visible on the southern horizon.

The description of the use of this quadrant, once it is made. If you want to determine the declination of every degree (of longitude), do exactly as I describe you. If we want to determine the declination of (the end of) Aries, we place the thread on the side of the thirtieth (division) of the altitude (scale). Then look at which place on the red circle — which is the declination circle (*dāʾirat al-mayl*[57]) — the thread will fall. Then take there the direction (of the sine along the horizontal lines). We find that the thread which we have taken there falls on twenty five degrees (*sic*![58]) and (some) minutes of the ninety degrees. This is the declination of Aries. Likewise, if you want the declination of (the end of) Taurus, take what is vis-à-vis 60 (units) of the altitude (on the declination circle). Operate with this in the same manner. The declination of (the end of) Gemini — (whose longitude) is ninety degrees (*juzʾ*) — is the complete declination (i.e., the obliquity). The declination of the end of Cancer is the same as the declination of the beginning of Gemini. The operation with the remaining (zodiacal signs) is similar.

If you want to determine (the amount) of the hours of daylight elapsed, ⟨97v⟩ look at how much is the meridian altitude for your day. If we assume it to be 60, we find it to reach the fifth circle, namely, the line which comes out of the extremity of the ninety unit scale, which is the sine (scale), (and goes to) the circle of the degrees. This is the (graduation) on which is (written) 130 (units) of the sine.[59] If we assume the altitude at the time of the measurement to be 30 (degrees), the thread will cross the fifth circle at some place on it. We take its direction toward the altitude (scale) and we find it to be at twenty five (degrees) and (some) minutes. We therefore know that one hour and two thirds and a fraction of the day have elapsed, because 15 (degrees) of the altitude (scale) represent one hour. This is for the beginning of the day. If the measurement is after midday (you will find) the (time) remaining of the day in hours.

If you want to operate (with) a sexagesimal sine, divide the sine (scale) of the quadrant into sixty (divisions).

Text 9: On finding the meridian with the astrolabe — $\mathcal{A}$: 198v–199r

Witty (pieces) from the work of Muḥammad ibn Mūsā al-Khwārizmī: On knowing the azimuth with the astrolabe.

If you want to know the azimuth with the astrolabe, measure (the altitude of) the sun when you want. Then look at which line corresponds to that altitude and put the degree of the sun (on the zodiacal belt) on its corresponding altitude circle.

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[57]The MS has 'circle of Aries'.

[58]The expected declination is of course $\delta(30°) = 11°40'$.

[59]We have indeed $150 Sin 60° = 129;54 \approx 130$.

Look at which line of azimuth reaches this altitude.[60] What you obtain will be the azimuth of that hour.

If you want to know the meridian line, and the sun is east-southerly, count the quantity of this azimuth on the quadrant where you took the altitude[61] and put the edge of the alidade on it. Then make the back of the astrolabe be parallel to the level ground, and rotate it to the right or to the left, until the shadow of the *kursī*[62] falls (completely) on the back of the alidade, or until the (solar) rays enter through the hole (of one of the sightings) and hence fall on the line which is on the middle of the alidade. If you can see it as this (i.e., as I have described), then the meridian line will be the diameter at the back of the astrolabe which has the suspensory apparatus on it.[63] Do the same if the sun is in the northwest, except that the suspensory apparatus in this operation will be on the northern side, whereas it was on the southern side in the first operation. ⟨199r⟩

If the sun is east-northerly, count [the quantity of the azimuth on the other quadrant] at the right of the quadrant with which you took the altitude, and let your counting be from below towards the side of the suspensory apparatus. Then put the edge of the alidade on this number, and make the back of the astrolabe be again parallel to the level ground. Rotate it to the right or to the left, until the alidade gets shadowed by the sightings (*kursī*), or until the (solar) rays enter through the hole (of the upper sighting) and fall on the medial line (of the alidade). If it occurs like this, then the meridian line will coincide with the diameter which goes through the suspensory apparatus, and the suspensory apparatus will be on the northern side. Operate in the same manner if the sun is west-southerly, except that the suspensory apparatus will be on the southern side.

We explain (this) to you: The sun is either north or south of the azimuth arc (on the astrolabic plate) which starts at the rising-point of Aries, goes through the zenith and ends at the setting-point of Aries. If the sun is in the (region) between this arc and the side of the centre of the astrolabe, then it is northerly when it is in the east and also when it is in the west. If it is outside of this arc in the (region) between it and the edge of the astrolabe, then it is southerly, be it in the east or in the west. This procedure (*ṣifa*) (only) applies to the astrolabe <on which> its (i.e., the sun's) azimuth is written from the azimuth arc of the rising-point of Aries until

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[60] I.e., which azimuth circle passes through the degree of the sun at that altitude circle.

[61] This is the upper-left quadrant at the back of the astrolabe.

[62] This term designates here the sightings of the alidade, not the throne of the astrolabe. This curious usage is also attested in a short text in $\mathcal{A}$:197r-v – see Ahmedov, ad-Dabbâgh & Rozenfeld (1987: 182–184) – as well as in a brief chapter of Ibn Yūnus' *Zīj*, in which he presents a method for determining the meridian with an instrument called a *musātira* – see Janin and King (1977: 255–256) and Charette (2003: 89).

[63] I.e. which is adjacent to the suspensory apparatus.

the meridian line and until (the line of) the pivot of the earth, 90 (degrees) on both sides.

As for the astrolabe whose azimuth numbering starts from the meridian line and ends at the pivot of the earth, 180 (degrees) fully on both sides, I mean the east and west (sides), then when you have taken what comes out to you in terms of azimuth, keep it in mind. If the sun is easterly, notice whether it is in the north or in the south, and then count what you have kept in mind from the right of the the beginning of the altitude.[64] Put the alidade on it and make the azimuth of the sun coincide with it according to what we have described.

Text 10: On the horary quadrant — $\mathcal{A}$: 196v–197r

The construction of a horary quadrant. If you want (to do) this, take a quarter circle and make two (sighting) parts on it for (taking) the altitude. On both sides of the quadrant trace two lines meeting at right angle, this angle being the position of the hole in which there is the thread with which the altitude can be determined. If you want the division of the hours, divide an amount of three quarters of the vertical line on the side of the quadrant into thirteen (equal) parts (and mark them). Put the compass at the centre of the quadrant and open it at each of those thirteen marks. Trace circular arcs with these (radii) that join the two straight lines that have been divided. The outermost arc will correspond to the beginning of Capricorn, while the innermost one will correspond to the beginning of Cancer. When you begin with the uppermost one, the first arc is for Cancer, the one next to it is for its middle, and the one next to it is for Leo. (Continue) half-sign after half-sign (in this manner) until you reach Capricorn. Then return along the lines and you will reach the middle of Capricorn, which is also the middle of Sagittarius. (Proceed) this way until you finish with the end of Gemini. Then you begin (again) with Cancer, God willing.

I have prepared for you a table of the altitude at the hours for the zodiacal signs and their middles: be aware of it (?). As for our computation of the altitude of the hours: if you want that, take the sine of (the meridian altitude at the beginning of) Cancer for the climate in which you are and keep it in mind. Then take the first *kardaja* of the sine and multiply it by the sine of the beginning of Cancer. Divide (the product) by 150, ⟨197r⟩ and the result will be the sine of its opposite sign (?). <. . . > this will be the altitude of (the sun at) the first hour of Cancer; keep it in mind. Take the first and second *kardaja*s and multiply them with the sine of the meridian altitude. Divide it by 150. Take the arc corresponding to the result, and this will be the (solar) altitude at the second hour. Then take the first, second and third *kardaja*s and operate with them in the same manner. The result will be

[64] I.e., the counting begins at the meridian line.

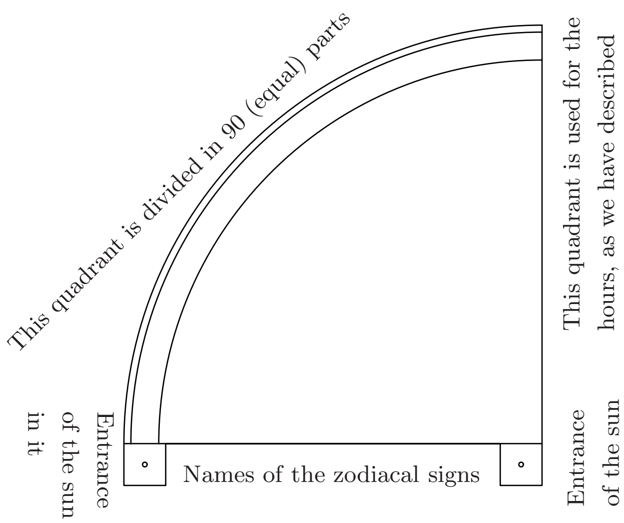
the altitude at the third hour. And likewise (for) the fourth, fifth and sixth hours. For other (signs) operate as you did for Cancer. It is the same (procedure) for all zodiacal signs.

Also, if you like, take fifteen degrees and take its sine. Multiply the result by the sine of the meridian altitude of Cancer. Divide the product by 150, and take the arc corresponding to the result, which will give you the (solar) altitude at one of the hours of Cancer (namely the first one). Then take thirty (degrees) and operate with it in the same way, (and so on) up to ninety (degrees). There will result the hours of Cancer. Do like this for all zodiacal signs.

I have prepared the table and the illustration. Be aware of that.

Table of the quadrant

Names of the signs	1	2	3	4	5	6
Cancer	14;0	29;0	44;0	59;0	73;0	81;0
half	14;0	29;0	44;0	58;0	72;0	80;0
Leo	14;0	29;0	44;0	57;0	70;0	77;0
half	14;0	28;0	43;0	56;0	67;0	73;0
Virgo	14;0	27;0	41;0	53;0	63;0	69;0
half	13;0	26;0	39;0	50;0	59;0	63;0
Libra	12;0	25;0	36;0	47;0	54;0	57;0
half	12;0	23;0	33;0	42;0	48;0	51;0
Scorpio	11;0	21;0	30;0	38;0	43;0	45;0
half	10;0	19;0	28;0	35;0	39;0	41;0
Sagittarius	9;0	17;0	25;0	31;0	35;0	36;0
half	8;0	16;0	23;0	29;0	33;0	34;0
Capricorn	8;0	16;0	23;0	28;0	32;0	33;0



Text 11: On a portable sundial (*mukḥula*) — $\mathcal{A}$: 192r

Construction of the *mukḥula* for the hours (*sc.*, as a sundial), which is suitable for the column, the whip (*sawṭ*)[65] and the stick. If you want (to do) this, take an instrument (made) of wood or (something) similar. Let the head of this sundial (*miqyās*) be five sixths of its base. Then divide it along its width[66] into six divisions, (one) for each (pair of) zodiacal sign(s), or, if you wish, (make also divisions) for each half (of a zodiacal sign). Take the length of this instrument and trace a line on a surface and put it aside. Let this line (correspond to) the length of the sundial and divide it into thirty equal parts: this will be the shadow scale. Then take (as the results) of the calculation (which are consigned) in the table (the vertical shadows of) the hours for each zodiacal sign, in terms of the graduated scale. Lay one foot of the compass atop (the sundial) at the place of the gnomon (and make a mark for each value of the table) until the hours are completed for all zodiacal signs. Then take a gnomon (*miqyās*) similar to what you see, whose outgoing (part) from the side of the instrument has five parts. (It has a) sharp head similar to the gnomon of the horizontal sundial and it revolves around it (the sundial) under the suspensory apparatus with which the sundial is being hanged. If you want to know the time of day elapsed in (temporal) hours, determine the position of the sun, suspend the instrument and face the line that goes through the sun. You will have written the names of the zodiacal signs on the lines. Bring the gnomon above (the appropriate zodiacal sign): the shadow will then fall upon the time of day elapsed in (temporal) hours, God willing.

[Table of the length of vertical shadows for each temporal hours (1–6), for latitude $\phi = 33°$, obliquity $\epsilon = 23;33°$ and gnomon length 5.][67]

hours	Cancer		Leo Gemini		Virgo Taurus		Libra Aries		Scorpio* Pisces	Sagittarius Aquarius		Capricorn	
1	1;13	+8	1;12	+4	1;11	+4	1;06	-1	—	0;58	+3	0;49	-3
2	2;38	+6	2;36	+4	2;33	+3	2;18[b]	-1	—	1;24	-18	1;29	-5
3	4;47	+18	4;38	+11	4;19	+6	3;39	-2	—	2;22	-4	2;09	-4
4	7;50	-9	7;35	+6	6;40	+1	5;15	-2	—	3;02	-2	2;44	-3
5	15;0	?[c]	13;38	+2	10;07	-2	6;50	-5	—	3;30	-4	3;07	-3
6	30;00	-2	22;02[a]	-3	12;32	-11	7;37	-5	—	3;41	-3	3;16	-2

* This column is missing. [a] Text 29;02 [b] Text 2;58 [c] Recomputation 22;05

[65] Although it may not be related to the intended meaning of a *mukḥula*-type sundial, it is interesting to note the following expression in Lane (*Arabic-English Lexicon*, s.v.): '*sawṭ bi-ẓill* : light entering from an aperture in a wall, in sunshine'.

[66] The text has 'length'.

[67] The table has been considerably mixed up: one column is missing, and as a result the zodiacal signs have been placed pairwise in the six remaining columns, in the following order: Cancer/Gemini, Leo/Taurus, Virgo/Aries, Libra/Pisces, Scorpio/Aquarius, Sagittarius/Capricorn.

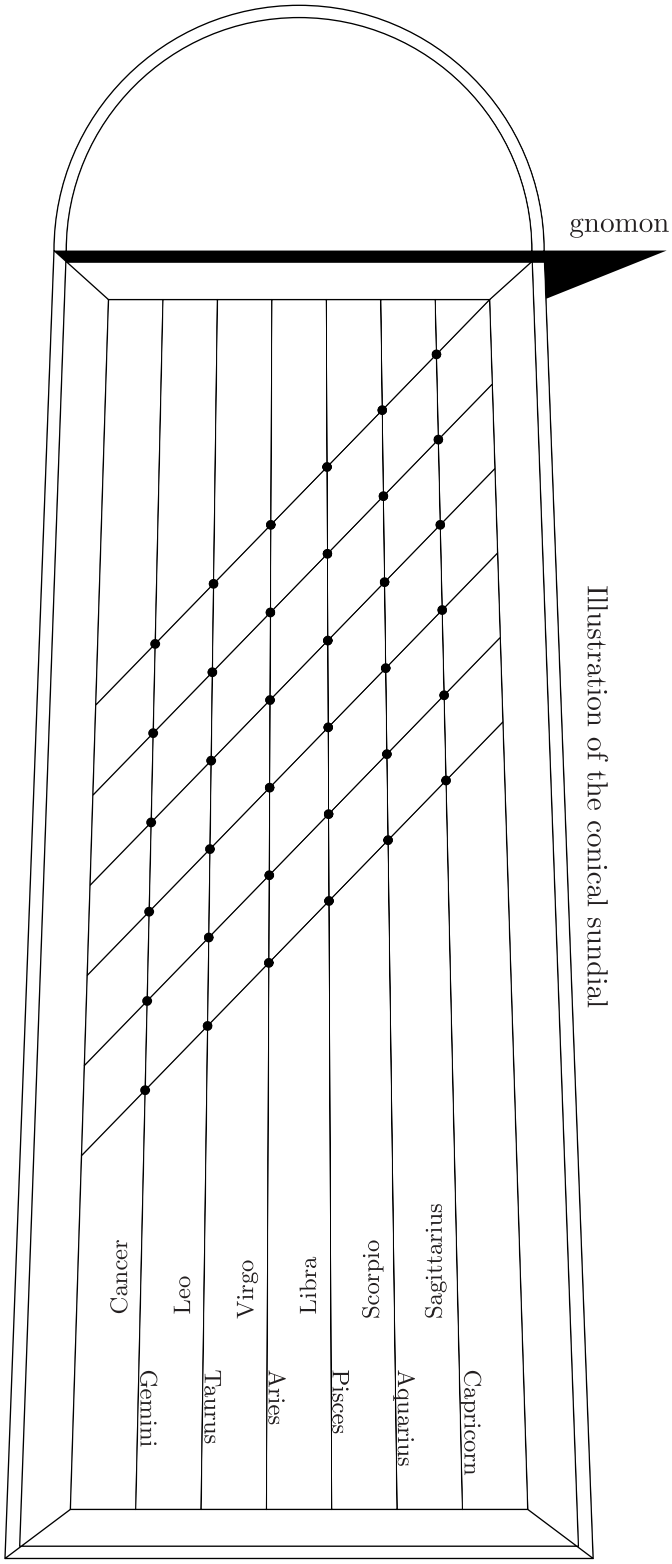


Illustration of the conical sundial

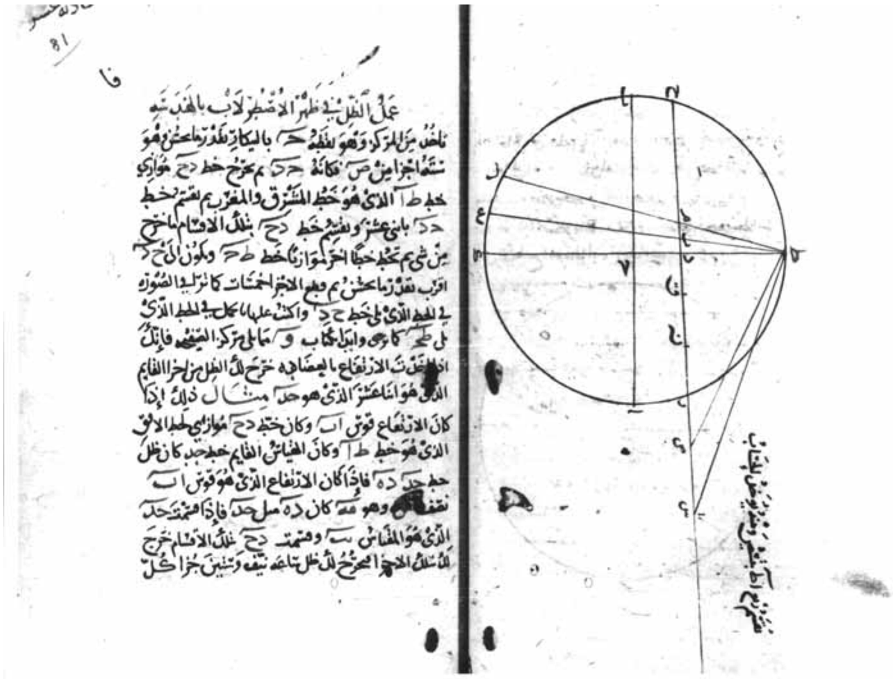


Figure 1: The latter part of Text 1 with the diagram showing the geometrical construction of altitude circles, and the beginning of the section on the shadow scale ($\mathcal{B}$:80v–81r), (courtesy Staatsbibliothek Preussischer Kulturbesitz, Berlin).

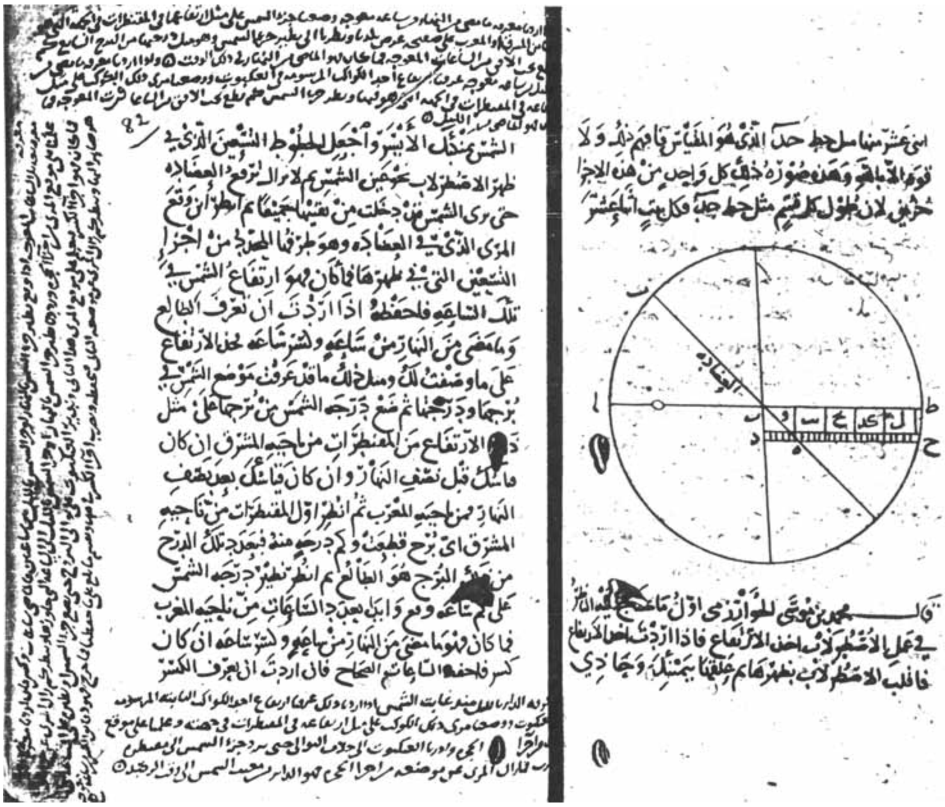


Figure 2: The end of Text 1 and the beginning of Text 2 in the Berlin manuscript ($\mathcal{B}$:81v–82r), with parts of the marginal notes edited in Appendix 1 (courtesy Staatsbibliothek Preussischer Kulturbesitz, Berlin).

Figure 3: The last sections of Text 2 and the beginning of Text 3 ($\mathcal{B}$:81v–82r), (courtesy Staatsbibliothek Preussischer Kulturbesitz, Berlin).

Figure 4: Some tables attributable to al-Khwārizmī found in the Berlin manuscript ($\mathcal{B}$:94v–95r), edited in Appendix 2 (courtesy Staatsbibliothek Preussischer Kulturbesitz, Berlin).

IV Commentary

IV.1 The construction of the astrolabe

The tentative attribution of this anonymous text to al-Khwārizmī, first made by David King,[68] is very appealing. First, we know from Ibn al-Nadīm that he composed treatises on both the construction and the use of the astrolabe. Second, the fact that a diameter of 150 – the Indian trigonometric base consistently used in al-Khwārizmī's writings – is used for the plate of the astrolabe, clearly points to the beginning of the ninth century. And as King already noticed, the style is not inconsistent with that of the following treatise for which we have a clear attribution to al-Khwārizmī. Yet things may not be that simple, for we will see below that the table for constructing the markings on the plates is very likely based on an obliquity of the ecliptic of $23°35'$ (see our analysis below),[69] which we can link to Ḥabash and several other Abbasid astronomers, but not to al-Khwārizmī, who seems to have preferred Ptolemy's value of $23°51'$. Of course, we cannot exclude the possibility that al-Khwārizmī, being alive at the time of the *mumtaḥan* observations and being apparently close to the caliphal court, might have at some point adopted the more modern parameter, which was even sanctioned by al-Ma'mūn. Be it as it may, for the sake of simplicity we shall refer to the author of this text as being al-Khwārizmī; the reader should nevertheless keep the speculative nature of this attribution in mind.

This treatise reveals an entirely different approach to the construction of the astrolabe to what we might expect from the formative phase of Islamic astronomy. Instead of adopting a geometrical method, al-Khwārizmī relies entirely on numerical tables, an approach further developed by al-Farghānī whose treatise on the astrolabe proved quite influential.[70] He does not explain the basic function underlying the operation with this table, but rather goes straight to explain its use. The table

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[68] "The treatise is anonymous and judging by the style of the Arabic and the nature of the contents is clearly an early ninth-century production. But more important is the fact that the treatise is copied immediately preceding al-Khwārizmī's treatise on the use of the astrolabe and also that the tenth-century bibliographer Ibn al-Nadīm mentioned that al-Khwārizmī wrote treatises on both subjects: in view of this, and also from a consideration of internal evidence, I see no reason to doubt that the treatise is also by al-Khwārizmī." King (1983a: 23–26, at 23).

[69] This parameter was first determined in 214 H as a result of the observations sponsored by the caliph al-Ma'mūn, a year after the astronomers had determined it to be $23°33'$. This new determination led the caliph to reject the first observations: see al-Bīrūnī (1962: 90–91); the value $23°35'$ was determined again a few decades later by the Banū Mūsā in Baghdad and by al-Battānī in Raqqa (see *ibid.*: 94–95).

[70] A paper by David King and the first author currently in preparation examines the tradition of making astrolabes by means of tables and surveys in details all extant texts and tables on the topic.

given on f. 78v contains two columns, labelled 'north' and 'south', in which two quantities, which we can designate by $f_N(\theta)$ and $f_S(\theta)$, respectively, are tabulated for arguments 1° to 89°. We can express the functions to which they correspond in modern notation as follows:

$$f_N(\theta) = R\ \tan\left(\frac{90-\theta}{2}\right) \qquad \text{and} \qquad f_S(\theta) = R\ \tan\left(\frac{90+\theta}{2}\right).$$

The function thus gives the distance from the centre of an astrolabic plate corresponding to the stereographic projection of a point of the celestial sphere having a declination θ.[71]

The radius R of the sphere of projection is not indicated in the text. We learn, however, that the radius of the plate is 150, which is indeed the Indian base adopted by al-Khwārizmī for his trigonometrical operations. Numerical analysis of the table (see below) yields an underlying parameter $R = 98;11$, with which we can associate an obliquity of $23°35'$, since $150/\tan(\frac{90°+23°35'}{2}) = 98;11$.

The altitude circles can be constructed from two quantities easily derived with the table. The distance of the northernmost point of the horizon from the centre of the plate is given by $f_N(90-\phi)$, and the radius of the horizon will be

$$\tfrac{1}{2}\Big\{f_N(90°-\phi) + f_S(90°-\phi)\Big\}.$$

The distance from the centre of the northernmost point of an **altitude circle**, when $h < \phi$, i.e., when it is projected between the horizon and the centre, is $f_N(90° - \phi + h)$, and the radius of the altitude will be

$$\tfrac{1}{2}\Big\{f_S(90°-\phi-h) + f_N(90°-\phi+h)\Big\}. \qquad (1)$$

When $h > \phi$, i.e., when the northernmost point is projected between the centre and the top, that distance becomes $f_N(90° - h + \phi)$, and the radius of the altitude circle is given by

$$\tfrac{1}{2}\Big\{f_S(90°-\phi-h) - f_N(90°-h+\phi)\Big\}. \qquad (2)$$

al-Khwārizmī omits to mention that when $\phi + h > 90°$, the first member of equations (1) and (2) should rather be $f_N(\phi + h - 90°)$.

The distances of the pointers for the fixed stars are simply given by $f_N(\Delta)$ or $f_S(\Delta)$ when the declination is northerly or southerly, respectively.

[71] Note that al-Farghānī rather more conveniently defined his basic function so that its argument is the arc measured from the north pole, which avoids his dealing with two different cases.

Construction of altitude circles by geometry (79r–80v)

It is not certain whether this section on constructing altitude circles geometrically really stems from al-Khwārizmī, since the radius of the astrolabic plate is here taken to be 60, instead of 150. The rather awkward procedure advocated in the text corresponds to the following geometrical construction (see the diagram on p. 139). We draw a circle of centre B with radius AB equal to 55 and a perpendicular segment BG of length 24. This forms a right-angled triangle whose hypothenuse GA determines the radius (of length $\sqrt{55^2+24^2} = 60;00,30 \approx 60$) of a second circle, which we draw separately. We then trace a line parallel to its horizontal diameter at a distance of 24 parts above its centre, so that it defines (within the circle) a chord of length 110. The horizon (inclined to the vertical diameter at an angle equal to the latitude) and the altitude circles are then projected stereographically onto the line representing the tropic of Capricorn.

This procedure, though yielding correct results, is both naive and clumsy. The parameter 55 for the radius of the plate appears to derive from a basic radius of 60 (55 being approximately equal to $60 \cos \epsilon$), so that it can be interpreted as the radius of either of the tropics on a celestial sphere of radius 60. But our author does exactly the converse and derives 60 from the quantities 55 and 24 by a geometrical construction!

The basic circles are then projected stereographically within a circle of radius 60, onto the 'tropic of Capricorn' instead of onto the 'equator'. The construction is purely artificial. It is not wrong, but it would have been much simpler to consider directly a circle of projection with radius 55, and to project onto its equator.[72]

Construction of a linear shadow scale (81r–81v)

The device described in this section for obtaining a shadow from an altitude (or conversely) represents a precursor of the shadow square that is omnipresent on the backs of astrolabes from the 9th century onwards, and which is featured in §15 of Text 2.[73] Instead of a square, our text describes a linear scale in the lower-right quadrant, parallel to the horizontal diameter and at a distance of six units below it. The text seems to suggest that these six units are taken on a radius of 90 units, but from the accompanying diagram it appears that we should actually assume a *diameter* of 60 units.[74] Those six units correspond to twelve units of shadow (i.e., digits), and the horizontal scale should be divided using the same units, with

[72]It happens, however, that the radius of the equator is nearly equal to $60 - 24 = 36$ and that the radius of Cancer is nearly equal to 24! But since the text does not go as far as to suggest to use these quantities, the correspondence might well be fortuitous.

[73]On the history of this device, see King (2004, Part XIIa, App. B).

[74]Hence our emendation ص → س

divisions at each 12 digits (labelled '6', '12', ..., instead of '12', '24', etc.), and further subdivided for each 2 digits, one subdivision corresponding to two digits, as specified at the end. With this scale it is possible to find the horizontal shadow corresponding to an altitude within the range *ca.* $12° - 90°$. It is well possible that al-Khwārizmī was the first to design such a shadow scale (cf. our remarks on p. 180 below).

Analysis of the table on f. 78v

We present in the following table al-Khwārizmī's entries as found in the unique manuscript and the associated errors in minutes corresponding to a recomputation with $R = 98;11$. This parameter indeed provides the best fit with the numerical data of the manuscript.[75] In the next column we have corrected obvious scribal errors and indicated the corrected error next to it. An asterisk means that the correction is uncertain.

IV.2 Text 2: The use of the astrolabe ($\mathcal{B}$:81v–91v)

al-Khwārizmī's treatise on the use of the astrolabe is the earliest such text preserved in Arabic.[76] Several texts on the astrolabe are documented from the eighth century, but none of them has survived. From the pre-Islamic period only two texts on the astrolabe have been preserved, namely the treatises of the sixth-century Alexandrian philosopher Johannes Philoponus,[77] and that of the Syrian bishop Severus Sebokht, written in Syriac in the second half of the seventh century.[78] Otto Neugebauer[79] has suggested that both works preserve the contents of a common source: the treatise on the 'small astrolabe'[80] by Theon of Alexandria. In fact, a comparision of al-Khwārizmī's and Sebokht's treatises makes it apparent that the former was likewise strongly dependent on Hellenistic sources that relate to Theon's lost treatise (see further our commentary on Text 7). These similitudes notwithstanding, al-Khwārizmī's treatise does contain several new types of problems and operations with the instrument. Thus the following topics appear for the first time in the astrolabe literature:

[75]We used the Levenberg-Marquardt method in the Statistics package of the Mathematica™ software. The result is the same with the corrected data.

[76]An alternative candidate is the treatise by ʿAlī ibn ʿĪsā (fl. *ca.* 830 AD), who was actually a younger colleague of al-Khwārizmī in Baghdād. From the style and contents of this work, though, we find very unlikely that it was written before the treatise edited in this paper. See Cheikho (1913) and the translation in Drecker & Schoy (1927).

[77]Philoponus (1839); idem (1981).

[78]Nau (1899).

[79]Neugebauer (1949: 242–243).

[80]The large one being the armillary sphere.

Table 3: Stereographic projection of a point of declination θ on the northern hemisphere

θ	MS	err	Correction	err	θ	MS	err	Correction	err
1	96;31	2			46	39;41	1		
2	94;11	-38	94;51	2	47	38;42	1		
3	93;12	2			48	37;42	1		
4	91;35	2			49	36;43	0		
5	89;59	1			50	35;44	0		
6	88;25	1			51	34;46	0		
7	86;53	1			52	33;48	0		
8	85;22	1			53	32;51	0		
9	83;52	1			54	31;57	3		
10	82;23	0			55	30;57	0		
11	80;56	0			56	30;1	0		
12	79;31	1			57	29;5	0		
13	78;8	2			58	28;9	0		
14	76;45	2			59	27;14	0		
15	75;23	3			60	26;59	41	26;19	1
16	74;2	3			61	25;24	0		
17	72;29	-10	72;39	0	62	24;29	0		
18	71;41	21	71;21	1	63	23;34	0		
19	70;2	0			64	22;40	0		
20	68;45	0			65	21;46	0		
21	67;29	0			66	20;52	0		
22	66;14	0			67	19;58	-1		
23	65;49	50	64;59	0	68	19;5	0		
24	63;45	-1			69	18;12	0		
25	62;33	0			70	17;19	0		
26	61;21	0			71	16;26	0		
27	60;10	0			72	15;33	0		
28	59;0	0			73	14;40	0		
29	57;11	-39	57;51	1	74	13;48	0		
30	56;42	1			75	12;55	-1		
31	55;34	1			76	12;3	0		
32	54;27	2			77	11;11	0		
33	53;19	0			78	10;19	0		
34	52;13	1			79	9;27	0		
35	51;7	0			80	8;35	0		
36	50;2	0			81	7;43	-1		
37	48;57	0			82	6;51	-1		
38	47;53	0			83	6;0	0		
39	46;50	0			84	5;8	-1		
40	45;46	-1			85	4;17	0		
41	44;45	0			86	3;26	0		
42	43;43	0			87	2;34	0		
43	42;42	1			88	1;43	0		
44	41;41	0			89	0;52	1		
45	40;41	1			90	0;0	0		

Table 4: Stereographic projection of a point of declination θ on the southern hemisphere

θ	MS	err	Correction	err	θ	MS	err	Correction	err
1	99;14	-41	99;54	-1	46	243;2	1		
2	101;40	0			47	249;16	1		
3	103;28	0			48	255;47	0		
4	105;18	1			49	262;36	0		
5	107;9	0			50	269;45	0		
6	109;2	-1			51	277;14	-2		
7	110;18	-41	110;58	-1	52	285;5	-4		
8	112;17	-40	112;57	0	53	293;21	-5		
9	114;18	-39	114;58	1	54	302;5	-6		
10	117;1	0			55	311;20	-4		
11	119;7	1			56	321;8	-1		
12	121;15	0			57	331;30	2		
13	123;26	0			58	342;28	4		
14	125;40	0			59	354;11	9		
15	127;57	0			60	366;20	-6		
16	130;17	-1			61	379;39	0		
17	132;41	0			62	393;49	1		
18	135;8	0			63	409;0	2		
19	137;35	-4			64	425;58	41	* 425;18	1
20	140;13	0			65	442;54	1		
21	142;14	-37	142;54	3	66	461;17	-38	461;57	2
22	145;34	0			67	482;36	1		
23	148;21	1			68	505;8	1		
24	151;12	1			69	529;46	1		
25	154;8	1			70	556;52	2		
26	157;40	32	* 157;10	2	71	586;45	2		
27	160;13	0			72	619;57	3		
28	163;24	0			73	657;0	2		
29	166;41	0			74	698;39	2		
30	170;4	0			75	745;44	-3		
31	173;38	6			76	799;42	4		
32	177;8	0			77	861;19	-26	* 861;49	4
33	180;50	0			78	934;11	2		
34	184;40	1			79	1019;43	3		
35	188;37	0			80	1122;48	34	* 1122;18	4
36	192;42	0			81	1247;36	4		
37	196;16	-40	196;56	0	82	1404;9	4		
38	201;19	1			83	1605;21	4		
39	205;12	-39	205;52	1	84	1873;30	3		
40	210;35	2			85	2248;11	-35	* 2248;51	5
41	215;28	1			86	2811;12	-24	* 2811;52 ?	16
42	220;32	1			87	3748;7	-81		
43	225;49	1			88	5624;11	-44		
44	231;19	1			89	11252;50	128	* 11250;50 ?	8
45	237;5	3			90	—			

1) degree of the ecliptic rising, culminating or setting with a star; 2) conversions between equal and seasonal hours; 3) astrological problems (houses, projection of rays, transfer of the years of nativities, ascendant of the year); 4) shadows; 5) prayer times; and 6) finding the azimuth and the meridian.

As we have mentioned in the introduction, al-Khwārizmī's treatise on the use of the astrolabe has been available in a German translation for more than 80 years. Our purpose is mainly to make a first edition of the Arabic text and to provide a more accurate translation than Frank's. Our commentary will not concern the whole text, but aims at clarifying and expanding the still valuable commentary that accompanies Frank's translation. We shall assume that the reader of this paper is familiar with the use of the astrolabe.[81]

§2c The first worked example concerns the basic use of the astrolabe. Given the terrestrial latitude (in this case Baghdad, $\phi = 33°$), the solar altitude and solar longitude, one is asked to find the ascendant, midheaven, and the time of day in temporal hours. In Baghdad (*madīnat al-salām*), the altitude of the sun is measured before midday as 24°, and its longitude is Scorpio 12° ($\lambda = 222°$). The ascendent is stated to be Sagittarius 9° ($\lambda_H = 249°$), the midheaven Virgo 22° ($\lambda_M = 172°$) and the nadir is said to be located in the third hour. To find the fractions of hour involved, one observes that the index (*murī*) of the rete indicates 263° on the limbus. If the nadir is placed on the hour-line corresponding to two complete hours, the index will point to 257°, and it will indicate 270° if placed on the third hour-line. The fractions of hour corresponding to 263° will be given by $\frac{263-257}{270-257} = \frac{6}{13}$. The time of the observation is thus $2\frac{6}{13}$ hours.

We can check these results by comparing them with exact recomputations. For the configuration given, the position of the index will correspond to the oblique ascension of the ascendant, which we recompute as 262.8°; the recomputed ascendant is 249.2° and the recomputed midheaven is 172.1°. Finally the recomputed time of day is $2.48 \approx 2\frac{6.2}{13}$ hours. All compare very well with the values given in the text. The accuracy of the results suggests they were numerically computed, rather than derived using an astrolabe.

§4a The examination of the astrolabe's accuracy by means of comparison against numerical computation became a frequent feature of the Islamic literature of the use of the astrolabe, as for example in al-Ṣūfī's extensive book.[82]

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[81] Other readers may consult any of the following modern treatments of the principle and use of the instrument: Michel (1947); North (1974); National Maritime Museum (1976); d'Hollander (1999); Morrison (forthcoming).

[82] See al-Ṣūfī (1986: 470-509).

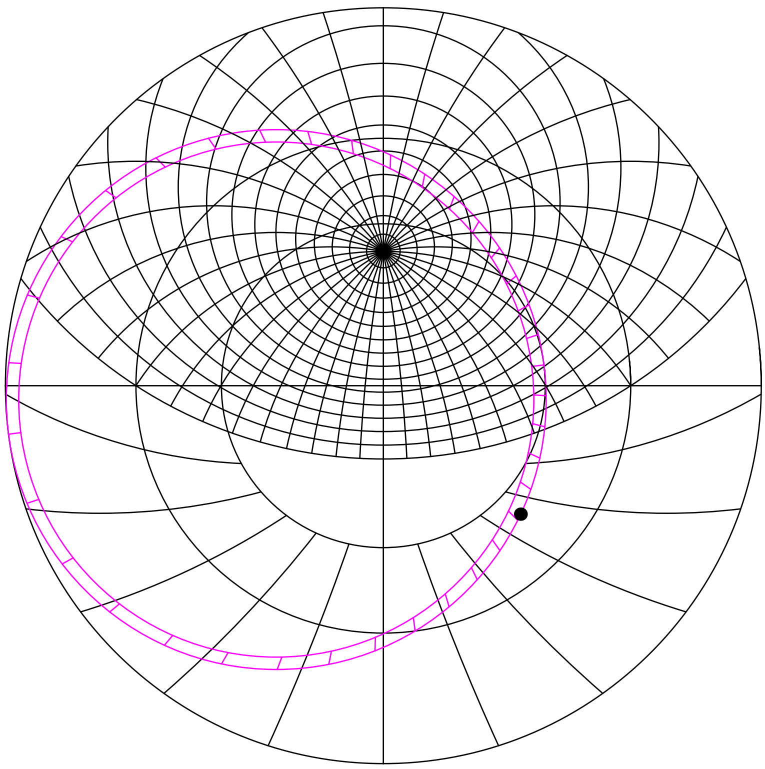

Figure 5: The configuration of the astrolabe for the first worked example

§4b The second worked example is very similar to the first one. It aims at establishing the faultlessness of the astrolabe. The parameters are the following (again for the latitude of Baghdad): altitude of the sun $h = 44°$, solar longitude $\lambda =$ Taurus15°. There results a time since sunrise of 2 hours and 1/6, or 53°15′ [recomputation 53°17′]; and the degree of midheaven is $\lambda_M =$ Pisces 24°2′ or 354°2′ [recomputation 354°3′].

§8 The procedure described here is sound in theory but quite inaccurate in practice.

§9b This is of course a rough approximation, since, if we express the latitude vector in equatorial coordinates, it assumes that its right ascension component is zero, which is true only at solstices. The same approximation is employed in §11b.

§12c The operation consists in finding the degrees of the ecliptic whose declination is equal to that of a particular fixed star. Of course this applies only to stars located within the celestial tropics.

§15 The shadow square has been a standard feature of Islamic and Western astrolabes for several centuries. Here we probably encounter its very first mention in the astrolabe literature. A similar device which may well have been its prototype was described in Text 1 (see p. 165).

The term *quṭr al-ẓill* (lit., 'diameter of the shadow') usually refers to the hypothenuse of the shadow, i.e., the equivalent of our modern secant function. Here however it rather seems to refer to the vertical shadow (of length $12 \tan h$), whereas the term *al-ẓill* simply means the horizontal shadow ($12 \cot h$).

§17–19 These are the inverse operations of those explained in §2a.

§20 This is the inverse of §3.

§21 This operation could be useful to find out whether an observation reported by someone else was made during the day or night.

§22 This seems to be the earliest description in the astrolabe literature of how to convert between equal and seasonal hours, an operation which became very common thereafter.

§23 The determination of the twelve astrological houses are likewise not mentioned in earlier sources. The terminology for each house is the standard one, and so is also their determination by means of the seasonal hour curves.[83]

§24 See the commentary on Text 6.

§25 and §26 The 'transfer of the year of nativity' is attained, when the sun reaches the same point of the ecliptic as it was at the time of birth. It is equivalent to a tropical year. The excess of revolution (*faḍl al-dawr*) is the excess of the tropical year over 365 days, expressed in equatorial degrees. In §25 and §26c, two different values are given for this parameter. In the first case this is given as $93°2'$, and in the second case as $93°15'$. The copyist noted that the second passage ($\mathcal{B}$:89v, 7–11) corresponds to a variant found by him in a different manuscript (*wa-wajattu fī nuskha ukhrā*). The first one indeed agrees with al-Khwārizmī's value of that parameter, as given in a list in the *Mumtaḥan Zīj* (MS Escorial ar. 927, f. 8r) and transcribed in Kennedy (1956: 147).[84] Now, there are several parameters for the length of the sidereal year that are associated with al-Khwārizmī, and each of them, when rounded to the nearest minute, corresponds to an excess of $93°2'$.[85]

[83]On the variety of definitions for the astrological houses in Islamic sources see Kennedy (1996).

[84]Our control of the parameters under discussion was facilitated by consulting E. S. Kennedy's parameter database, compiled in electronic form by our colleague Benno van Dalen, a preliminary version of which is made accessible through the internet at http://www.rz.uni-frankfurt.de/~dalen.

[85]There is a considerable confusion around the values used by al-Khwārizmī for the length of the sidereal year (and related parameters): the only value which appears to be secure is that of 365;15,30,22,30 days (corresponding to an excess of 93;2,15°), which is said to pertain to the Sindhind tradition, and which can indeed be linked to Brahmagupta. Two different values of the anomalistic mean motion per day were 'squeezed' by Kennedy from the same table of al-Khwārizmī (Suter 1914: 115), namely 0;59,8,10,21,30,54 and 0;59,8,10,21,44,35, and correspond to excesses approximately equal to 93;2,17° and 93;2,8°, respectively. The excess of $93°2'$ found in our astrolabe

The second value of 93°15′, which the copyist of our text says he found "in a different manuscript copy", is associated, in the same list contained in the *Mumtaḥan Zīj*, with the *Zīj-i Shāh* and with Māshāʾallāh and al-Ḥasan ibn Sahl ibn Nawbakht. This parameter is also linked to the Persian tradition and to the astrologer Māshāʾallāh by al-Hāshimī.[86] On the other hand, al-Majrīṭī's recension of al-Khwārizmī's *Zīj*[87] also mentions a year length of 365;15,32,30, which corresponds precisely to an excess of 93°15′. But this may not necessarily be due to al-Khwārizmī, and the passage in §26c is probably interpolated from a different source.

§27 The underlying latitude of Kufa is here 32°, which was certainly rounded from al-Khwārizmī's value of 31°50′.[88] The underlying latitude of Rayy, 37°, is however problematic, for in all versions of al-Khwārizmī's geographical table it is given as 35°45′; only five attested sources give a latitude that could be rounded to 37°.[89]

§28a–b 18° is a most common value for the solar depression at twilight.[90]

§28c–e None of the definitions of the midday and afternoon prayers mentioned here are attested elsewhere. They also differ widely from the commonly used definitions in terms of shadow increase. For further discussion the reader is referred to King (2004: II-3.1 and IV-4.5).

§29 The addition of azimuth curves on astrolabic plates was an innovation of Abbasid astrolabe-makers in the late eighth or early ninth century. This section probably contains their very first mention in the literature. The reference to the determination of the meridian in the last paragraph is not clear; on this topic see however Text 9.

§30 This section, which explains an approximate method to determine the time of moonrise, is not directly related to the use of the astrolabe, but this instrument can be used to determine the requested ascensional difference between the luminaries. The text is corrupt at places. Our corrections agree with those suggested by Frank, to whom we refer for a more detailed commentary.[91]

§31 The longitudes of Baghdad (70°) and Damaskus (60°) mentioned in this example agree perfectly with the data in the anonymous geographical table related to

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treatise and associated with al-Khwārizmī in the *Mumtaḥan Zīj* can be explained by rounding any of the above three values of the excess of revolution to the nearest minute.

[86] Haddad, Kennedy & Pingree (1981: f. 132r).

[87] Suter (1914: 42).

[88] Kennedy & Kennedy (1987: 190).

[89] Kennedy & Kennedy (1987: 284). These sources are MLH-YAQ, ATH-FID, BAT, TOL and MRS.

[90] See King (1997); cf. idem (2004: II.4.10).

[91] Frank (1922: 28-29).

al-Khwārizmī in $\mathcal{A}$:194v–196r.[92]

IV.3 On a compass for finding the prayer-times

The first half of this section explains the construction of a special 'compass' for finding the times of afternoon prayers that depend on shadow lengths. The compass has two quadrangular legs with square base. An iron pin (*qalam*) is attached at the base of each leg. One side of one of the legs, called the western side, bears a scale divided as a 4×4 grid. The table to which it is referred in the text is actually found on f. 94r (see **Table 2**).[93] The arguments in the first column contain the names of the zodiacal signs from Aries to Virgo, the signs of equal declination being in the same square. The following three columns contain the results of 'the calculation as represented [in the table]', namely the shadow lengths at the midday prayer, at the beginning of the afternoon prayer, and the end of the afternoon prayer.[94] One side of the other leg, called the eastern side, will be inscribed in the same way, from Libra to Pisces. The other sides of the compass are called the northern side, or front of the compass, and the southern side. They are divided into twelve equal parts, and fixed together by a nail or rivet of iron (*mismār ḥadīd*), both sides opposite the zodiacal scale being put on top of each other. So the compass consists of two legs attached together and inscribed with two scales, one with which one can find the shadow lengths at various prayer times for each zodiacal sign, and another one which will serve to measure the shadow lengths.[95]

The use of the compass is straightforward. On a level ground, the legs of the compass are brought vertically alongside each other and their pins are sticked into the ground. In this manner the compass can be used as a vertical gnomon. After a mark has been made at the end of the shadow, the compass is opened horizontally

[92]This table is edited in Kennedy & Kennedy (1987: 409–412) as source KHZ. It is interesting to note that in al-Khwārizmī's *Kitāb Ṣūrat al-arḍ* (KHU in *ibid.*) the longitude of Baghdad is 73°, whereas Damascus has also 60°.

[93]It is obvious that the table belongs to this text, because it is labelled 'north', 'south', 'east' and 'west', which only makes sense on the instrument. This table is discussed in King (2004, I: 233–234), without reference to the treatise it actually belongs to. However King (1983a: 7) had already shown that it in fact belongs to Text 2.

[94]Frank & Wiedemann (1920–21: 124, n. 4) assumed that the second column should be filled with strokes at every five degrees, the third column with strokes at every degree and the fourth column with the shadow lengths at the afternoon prayer.

[95]A similar instrument, but only to measure 'standardized' parts of digits or feet, is described by Muḥammad b. Abī Bakr al-Fārisī (Yemen, d. 1278/79) in his folk astronomical treatise *Kitāb Tuḥfat al-rāghib wa-ṭurfat al-ṭālib fī taysīr al-nayyirayn wa-ḥarakāt al-kawākib*. On al-Fārisī and his folk astronomical treatise, see King (1983b: 23–24); on the instrument itself see Schmidl (to appear).

to form a 24-digit scale with which that shadow length can be measured.[96] The result is then compared to the entries in the table engraved on the western and eastern sides of the compass. The author recommends to wait for a while when the shadow length is shorter than that of the expected prayer, but astonishingly he also recommends to wait when it is too long! Could this allude to a time shortly before midday when the shadow is still decreasing?

The shadow lengths in Table 2 are given as integer numbers. The midday shadow lengths agree only very roughly with the values we might expect (assuming that the *ẓuhr* occurs indeed at midday). We have been able, however, to figure out how the values might actually have been computed.

$$\text{shadow at the } \textit{ẓuhr} = \Big\langle \operatorname{Cot}\langle 90^\circ - \phi + \delta \rangle \Big\rangle,$$

where $\langle\theta\rangle$ is the integer part of θ, and $\operatorname{Cot}\theta$ gives the horizontal shadow of a vertical gnomon of length 12 (i.e., $\operatorname{Cot}\theta = 12\ \cot\theta$). Recomputation of the midday shadow according to the above formula is shown in the following table next to the value tabulated in the manuscript. Only three entries diverge, which we have underlined; all three of them could be explained as a result of a scribal error. As for the lengths of the shadow at the beginning and end of the *ʿaṣr* prayer, the entries in the manuscript are close to, but do not really coincide with the standard definition, according to which they are given by adding to the midday shadow the gnomon length 12, and twice the gnomon length, 24, respectively. Our recomputations below are based on those standard definitions. Here the discrepancies can not be merely explained through scribal errors, but no clear computational pattern is discernable.

[96] When the shadow exceeds 24 digits, it is not difficult to measure n segments of 24 digits, and then the remaining digits.

λ'	*ẓuhr*	rec.	beg. *ʿaṣr*	rec.	end *ʿaṣr*	rec.
90	2	2	13	14	25	26
84	2	2	13	14	25	26
78	2	2	14	14	25	26
72	2	2	14	14	25	26
66	2	2	14	14	25	26
60	2	2	14	14	25	26
54	2	2	14	14	26	26
48	3	3	15	15	27	27
42	3	3	16	15	28	27
36	4	4	16	16	28	28
30	4	4	17	16	28	28
24	5	5	17	17	29	29
18	6	5	17	17	29	29
12	6	6	18	18	31	30
6	7	7	19	19	31	31
0	8	7	20	19	32	31
-6	8	8	20	20	32	32
-12	9	9	21	21	34	33
-18	10	10	22	22	34	34
-24	11	11	23	23	36	35
-30	12	12	24	24	36	36
-36	12	12	25	24	36	36
-42	13	13	25	25	38	37
-48	14	14	26	26	39	38
-54	16	15	28	27	39	39
-60	16	16	28	28	41	40
-66	17	17	29	29	41	41
-72	17	17	29	29	42	41
-78	18	18	31	30	43	42
-84	18	18	31	30	44	42
-90	18	18	31	30	44	42

IV.4 On a plate for finding the times of moonrise and moonset

The 'moon plate' whose construction is described in this section is a rather simple device for finding approximately the times when the moon rises and sets, and the duration of its visibility in the night sky. The title also implies that this circular plate can be used to measure the altitude. No indications are given about the use of the instrument. The extremities of its two perpendicular diameters are labelled 'north', 'west', 'east' and 'south'. Three graduated rings enclose the outer rim: the outer one has 18 subdivisions in each quadrant; they are numbered from 5 to 90 starting at the east and west and until the north and south, as on the diagram on p. 153. The next graduation has subdivisions for each single degree. The inner ring, called 'circle of the number of nights' (*dāʾirat ʿadad al-layālī*) is divided into 28 parts along each of the southern and northern halves. On the southern half the numbers 1 to 28 are written from east to west. The text then says to write on the northern half computed numbers taken from a table (*wa-ktub ʿalayhā al-ḥisāb ʿalā mā fī 'l-jadwal*). There are indeed such numbers written on the scale of the diagram in the manuscript, in a mixture of *abjad* and Hindu numerals; obviously they have considerably suffered at the hands of successive copyists. Fortunately, the underlying function being (quasi) linear, it is very easy to reconstruct the original numbers, which are represented on the diagram in our edition and translation. Within the northwest quadrant is inscribed: '(the moon) rises at midnight' (*yaṭlaʿu niṣf al-layl*), and similarly in the northeastern one: '(the moon) sets at midnight' (*yaghību niṣf al-layl*). Finally, the plate is fitted with an alidade.[97]

The plate can be used to determine the time of moonrise or moonset as follows: Starting from new moon, the moon rises every day approximately 50′ later than on the previous day. If we place the pointer of the alidade on the number corresponding to the day within the lunar month on the 'circle of the number of the nights', the other pointer will indicate the time of moonset of the nights from new moon to full moon or the time of moonrise of the nights from full moon to crescent. The first number indicates the hours, and the second one the sixths of an hour. The northwestern scale indicates thus the rising times in seasonal night hours, counting from sunset to sunrise, whereas the northeastern one indicates the setting times. Transposing the data on these scales in tabular form and writing the values of time in hours and minutes we thus have:

W													N
28	27	26	25	24	23	22	21	20	19	18	17	16	15
12	11h10′	10h20′	9h30′	8h40′	7h50′	7h	6h	5h10′	4h20′	3h30′	2h40′	1h50′	60′
N													O
14	13	12	11	10	9	8	7	6	5	4	3	2	1
12h	11h10′	10h20′	9h30′	8h40′	7h50′	7h	6h	5h10′	4h20′	3h30′	2h40′	1h50′	60′

IV.5 On the different species of astrolabes

This short passage gives a nomenclature of astrolabes that only depends on the number of altitude circles drawn on the plates. It does not deal with unusual types of astrolabes that involve either a combination of northern and southern projections – as on the crab or myrtle astrolabes – or non-stereographic projections – as with the melon astrolabe.[98] The different types mentioned are the complete (*tāmm*), bipartite (*niṣf*), tripartite (*thulth*), quinquepartite (*khums*), sexpartite (*suds*) and decempartite (*ʿushr*) astrolabes. The plate of a complete astrolabe has 90 altitude circles, of a bipartite 45, a tripartite 30 and so on, because 'the astrolabe is called

[97] A suspensory apparatus is neither mentioned in the text nor drawn on the diagram. The purpose of the altitude scales is not clear. Perhaps it is a standardized procedure to have altitude scales on astronomical plates, also helpful for the inscription of the moon scales, or, most likely, it is intended to be inscribed on the back of an astrolabe.

[98] On non-standard astrolabes, see Lorch (1994), Charette (2003: 63–83) and Kennedy, Kunitzsch & Lorch (1999).

(after) the quantity between two circles'.[99] Severe Sebokht (fl. 7th c. AD) in his treatise on the astrolabe mentions the bipartite and tripartite versions.[100]

There is also a thirteenth-century Latin text on the astrolabe which describes this nomenclature in a similar way.[101]

IV.6 On projecting the rays with an astrolabe

The procedure for performing the astrological operation of 'projecting the rays'[102] with the help of an astrolabe is here equivalent to, but far clearer than, that described in §24 of Text 2. The same method is found in several treatises on the use of the astrolabe.[103] The most thorough mathematical treatment of this topic was given by al-Bīrūnī in his *Qānūn* (*maqāla* 11, *faṣl* 3).[104]

IV.7 On Ptolemy's five terrestrial zones

This short passage on 'Ptolemy's definition of the five terrestrial zones' describes a division of the world different from the seven climates known from Classical Antiquity.[105] The five zones described here include the inhabited as well as the uninhabited world, spanning all latitudes from the north to the south pole. This division of the terrestrial sphere was also known in Antiquity and is in fact earlier than Ptolemy and Posidonius, but it is doubtful that it really goes back to Thales, Pythagoras or Parmenides.[106] These five zones are delimited by the arctic and antarctic circles

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[99] On the terminology see Hartner (1939: 2539).

[100] See Nau (1899: 89).

[101] See Kunitzsch (1994). The first *distinctio* begins with "Incipit liber de diuersis speciebus astralaborium". According to Kunitzsch, the author of this anonymous abridged treatise could be Adelard of Bath.

[102] On this astrological operation see Kennedy & Krikorian-Preisler (1972), and Hogendijk (1989).

[103] For example Abū al-Ṣalt – *faṣl* 76 in al-Marrākushī's recension (al-Marrākushī 1984, II: 290). The latter notes that this is the method of "some of the ancient (astrologers), but not that of al-Battānī, although it is very close to the correct result. Al-Battānī's method is the one adopted by the majority of modern astrologers, but it is not possible to use it with an astrolabe, except if it is a southern one (?)". al-Ṣūfī in chapters 158–159 of his treatise in 402 chapters presents two different and less simple methods: see al-Ṣūfī (1986: 207–215); cf. idem (1995: 194–198).

[104] al-Bīrūnī (1954–56).

[105] As described in the classic study Honigmann (1929). The seven climates cover the inhabited world of the northern hemisphere between the equator and the arctic circle. The breadth of each climate is defined by the length of daylight at summer solstice, in successive steps of half an hour.

[106] See Harley & Woodward (1987: 136), 169; Dicks (1960: 23) and Szabó (1992: 104f).

and the tropics of Cancer and Capricorn.[107] Sometimes the equator is taken into consideration as a fifth limit, so that six zones are counted.[108]

In our text the limits depart from the standard scheme, as they are defined as follows:[109]

first zone	36°9′ N
second zone	30° N
third zone	[23]°51′ N and S
fourth zone	30° S
fifth zone	36°9′ S
sum	180°

The limits of the second and the fourth zone look at first sight arbitrary, as they have been reduced to two belts of 30° instead of 42°18′. Hence the limits between the first and second zones or the fourth and fifth zones coincide with the parallels of 53°51′ N and S — instead of 66°9′ which corresponds to the arctic and antarctic circles. Interestingly, the very same system is described in Chapter 24 of Severus Sebokht's astrolabe treatise, where it is likewise attributed to Ptolemy.[110] Just before, Sebokht had described another, closely related scheme attributed to "the philosopher", who Neugebauer has shown to be Theon of Alexandria.[111] The zones are divided as follows (again from north to south poles): 36°, 30°, 48°, 30°, 36°. The scheme, which is equivalent to one featured in our text, rounded to the nearest degree, is

[107] The basis of this division is either based on a transfer of the celestial circles defined by the yearly path of the sun – see Aujac (1974: 195) – or more probably on the behavior of the midday shadow: see Szabó (1992: 114–115); Berggren & Jones (2000: 85); Harley & Woodward (1987: 169).

[108] Szabó (1992: 104–105 and 115, fig. 7).

[109] In the manuscript the value for the third zone is given as twice 47°51′, which of course should be emended to 23°51′, so that the third zone spans twice the obliquity, i.e., 47°42′ (the degrees for the whole zone have obviously contaminated those of its half given in the text).

[110] Nau (1899: 301):

> Chapitre xxiv. Il y a encore une autre division faite par l'astronome Ptolémée. D'abord la zone arctique de 36°9′. En second lieu la zone d'été de 30°. En troisième lieu la zone équatoriale qui est de 23°51′ au nord et autant au sud. La quatrième est la zone d'hiver de 30°. La cinquième est la zone antarctique de 36°9′. Cela fait en tout 180 degrés; il est évident qu'ici encore ce philosophe nous apprend à mesurer la latitude depuis le pôle nord jusqu'au pôle sud.

[111] Neugebauer (1949: 243). Theon's astrolabe treatise – lost but whose table of contents is known through al-Yaʿqūbī – also had a chapter on the division of the terrestrial sphere into zones. See Klamroth (1888: 20).

well-attested in Classical Antiquity, for it is mentioned by the astronomer Geminus (fl. *ca.* 70 BC).[112] In such divisions of the terrestrial sphere the terms 'arctic circle' or 'antarctic circle' describe parallels that define the limits of visibility of fixed stars at a particular location, in this case for a latitude of 36°, intended for Rhodes.[113] In Classical Antiquity it was apparently a convention to use the parallel of Rhodes ($\phi = 36°$), situated in the middle of the inhabited world, even when one's locality had a different latitude. Consequently the parallel circle of 54° defining the limit of the ever visible stars for Rhodes was often used more generally.[114]

Now Sebokht and al-Khwārizmī probably did not have a latitude of 36°9′ in mind. We think, with Neugebauer, that Sebokht (or his source) rather confused the minutes of the second and fourth zones with those of the first and fifth zones.[115] The original scheme was more likely to have been: 36°, 30°9′, twice 23°51′, 30°9′ and 36°, the difference with Geminus and Theon being that a more accurate value of the obliquity is used, namely that of Ptolemy, which probably explains the – most likely unfounded – attribution to the latter. The fact that al-Khwārizmī reproduces Sebokht's erroneous description could either mean that he had access to a translation or adaptation of his Syriac treatise, or that he relied on the same Greek source as Sebokht, which would have already contained the confusion.

IV.8 The sine quadrant

This text contains the earliest description of the sine quadrant known to date. In view of the style and the fact that it advocates a trigonometric base of 150, attributing it to al-Khwārizmī does not seem unreasonable. And the fact that the thirteenth-century astronomer al-Marrākushī in his encyclopedic treatise on spherical astronomy and instruments informs us that some people call the sine function *al-jayb al-khwārizmī*, that is, the sine (quadrant) of al-Khwārizmī, lends further credence to this attribution.[116] There are other instances where al-Marrākushī refers to the sine, shadow and declination scales on the back of an astrolabe (cf. p. 165 above)

[112]Geminus (1898: 58ff).

[113]See for example Aujac (1974), Harley & Woodward (1987: 140–141 and fig. 8.8); Szabó (1992: 104ff).

[114]Aujac (1974: 196); Dilke (1987: 185) and Aujac, Harley & Woodward (1987: 170). Later the concept of the arctic circle as the limit of visibility for a specific latitude came into oblivion. . Cf. Dicks (1960: 166): "Latin writers such as Manilius, Hyginus and Martianus Capella, not understanding the Greek usage of variable 'arctic' and 'antarctic' circles, took them as fixed at 36° from each pole ..."

[115]Cf. Neugebauer (1949: 253).

[116]"*wa-min al-nās man yusammī hādhā al-jadwal al-jayb al-khwārizmī*": al-Marrākushī (1984, I: 39); translation Sédillot (1834: 120).

as *jadwal al-jayb al-khwārizmī*, *jadwal al-ẓill al-khwārizmī*, and *al-ẓill al-khwārizmī wa-l-mayl al-khwārizmī*, respectively.[117]

The sine quadrant described by al-Khwārizmī – assuming he really is the author – bears along the outer arc an altitude scale divided into 90 equal parts, and a scale along the vertical radius divided into 150 equal units, thus assuming an Indian trigonometric base instead of a sexagesimal one. A thread with plummet is attached at the centre. We can also assume that a pair of sightings are found along the vertical radius Horizontal lines go from each 5° graduation of the altitude scale to the 150 unit scale. Although the text is obscure in this respect, it seems that the instrument also bears concentric circular arcs whose radii coincide with the extremity of those horizontal lines along the vertical scale. Our reconstruction of the instrument is shown in the figure below. There is an additional circular arc called *dāʾirat al-mayl*[118] which is drawn in red ink. This information suggests an instrument of wood or a similar material instead of metal.[119] As its name says, it is used to determine the solar declination.

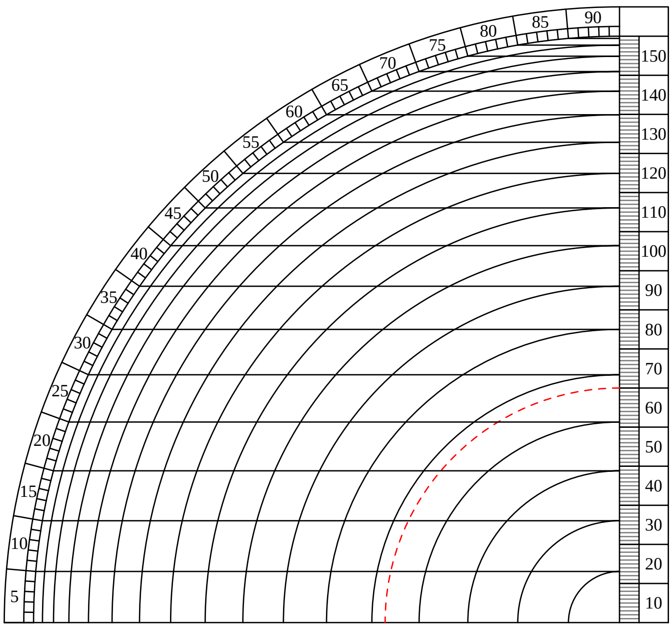

Figure 6: A reconstruction of al-Khwārizmī's sine quadrant

To find the declination, one lays the thread on the outer scale at the graduation corresponding to the ecliptic distance of the solar longitude to the nearest equinox.

[117] See al-Marrākushī (1984, I: 250; II: 200).

[118] The manuscript has wrongly '*dāʾirat al-ḥamal*'.

[119] Unfortunately the manuscript has a wormhole precisely at the place where the material of the instrument appears to be mentioned.

At the intersection of the thread with the 'declination circle', one follows a horizontal line to the outer scale, and this will give the declination In the text a numerical value of 25° and some minutes is given for the declination of 30°, which is of course absurd. There follows a procedure to determine the time of day in seasonal hour by means of the instantaneous solar altitude and the meridian altitude. Since it is valid for all latitudes, this procedure is based on the well-known universal approximate formula for timekeeping:[120]

$$\mathrm{Sin}\, h_i = \mathrm{Sin}\, h_m \ \ \mathrm{Sin}(15i)/R$$

Though approximate, the above formula yields excellent results for tropical and Mediterranean latitudes ($\phi < 40°$) Unfortunately the graphical procedure described in the text is erroneous, since it is equivalent to the formula $\mathrm{Sin}\, 15i = \mathrm{Sin}\, h \ \ \mathrm{Sin}\, h_m$. The error is further confirmed by the numerical example given for $h_m = 60°$ and $h = 30°$, which is said to yield a time of one hour and two thirds. We have indeed

$$\mathrm{arcSin}(\mathrm{Sin}\, 30° \ \ \mathrm{Sin}\, 60°)/15 = 25;40/15 \approx 1 \text{ hour and } 2/3\,!$$

whereas the correct answer would have been two hours and one third.

IV.9 On finding the meridian with the astrolabe

The title of this text, "Witty (pieces) from the work of Muḥammad ibn Mūsā al-Khwārizmī: On knowing the azimuth with the astrolabe", seems to imply that it is extracted from a larger work. The first paragraph concerns the simple operation of finding the azimuth with an astrolabe whose plates bear azimuth circles. This procedure is also described in more detail in §29 of Text 2. Even though the text is titled 'on finding the azimuth' it actually deals with the determination of the meridian.

This operation is divided into four cases according to the four quadrants within which the sun can be located: south-east, north-west, north-east, and south-west. After setting the alidade vis-à-vis the value of the azimuth on the altitude scale of the back, the astrolabe is laid horizontally. When the alidade is perfectly oriented toward the sun, the vertical (north-south) diameter on the astrolabe will correspond to the meridian. Depending in which quadrant the sun is located, the throne may be southerly or northerly. This is because the altitude scale on the back is engraved only along the rim of the two upper quadrants.

After describing the above procedure, some additional information concerning the determination of the azimuth on the plate of the astrolabe is provided. al-Khwārizmī writes that if the sun is located between the prime vertical (the azimuth circle going through the east and west) and the centre of the plate, it will have a northerly

[120] See King (2004, II, Part XI).

azimuth, and a southerly one if it lies outside of it. The next remark tells us that two conventions for measuring azimuths coexisted during al-Khwārizmī's times: the most common was to measure it from the east and west, but a numbering from the north was also possible, going up to 180° at the south.

Similar methods for finding the meridian are described by al-Ṣūfī (Rayy, 903-986) and Ibn al-Samḥ (Granada, b. 979) in their treatises on the use of the astrolabe.[121] According to Frank (1922: 27), we also find them in the treatises of [pseudo-]Māshāʾallāh[122] and Abū al-Ṣalt[123] (Egypt and al-Mahdiyya, b. 1067).

IV.10 An horary quadrant for a specific latitude

This text succinctly describes the construction of a standard horary quadrant with equidistant day-arcs (see Figure 7). It represents the first documented description of this instrument.[124] On both radii of the quadrant (or radius R), a mark is made at a distance of $R/4$ from the centre, and the two segments from those marks to the extremities of the quadrant are divided into thirteen equal parts, which define the radii of the concentric day-circles on the quadrant. Here the outermost day-arc represents Capricorn. Each hour-line is to be drawn by joining 13 points marked on the day-arcs of each zodiacal sign and its half. For that purpose, a table of the solar altitude at each 15° of solar longitude is provided for each of the six seasonal daylight hours before (or after) midday.

To compute the entries in this table, the text advocates using the approximate formula[125]

$$\operatorname{Sin} h_i = \operatorname{Sin} h_m \ \operatorname{Sin}(15i)/R,$$

which we have already encountered in Text 8 on the sine quadrant, where its use was implicit (but with an incorrect procedure). Here the trigonometric base is taken as $R = 150$, which again could be a sign of al-Khwārizmī's authorship. The use of the term *kardaja* to designate the sines of each multiple of 15° reveals in this text the influence of Indian trigonometry.[126] The above formula is explained twice in the

[121] al-Ṣūfī, in his treatise in 402 chapters, devotes chapters 161–162 and 164–166 to this topic; see al-Ṣūfī (1986: 217–232); cf. idem (1995: 199–204). On Ibn al-Samḥ see Villadrich (1986: 130–131).

[122] Kunitzsch (1981) has shown that the likely author of a treatise on the construction and use of the astrolabe by 'Messahala' is in fact Ibn al-Ṣaffār (early 11th c.), like Ibn al-Samḥ a disciple of Maslama al-Majrīṭī.

[123] MS London, British Library, Or. 5479, ff. 22r-v (*bāb* 55). Cf. *faṣl* 45 in al-Marrākushī's recension (al-Marrākushī 1984, II: 277–278).

[124] On the horary quadrant see Charette (2003: 116–139).

[125] On the history of this formula see King (2004: vol. 2, Part XI).

[126] On this word see Woepcke (1854) and Nallino (1944: 220-221).

text, once by means of *kardaja*s, and again by mentioning instead the sines of 15°, 30°, etc. Perhaps the term *kardaja* was becoming old-fashioned when this text was composed.

The table accompanying the text is indeed based on the above formula, but for the specific latitude of 33° (for Baghdad). **Figure 7** shows a reconstruction of the horary quadrant described in Text 10. Three families of lines are superposed on the figure, showing the hour-lines constructed from the numerical entries in the table (continuous), and those deriving from the exact formula (dotted) and the above approximate formula (dashed).

IV.11 A portable conical sundial

This short tract describes a portable vertical conical sundial called a *mukḥula*. This name designates a container for eye cosmetic (*kuḥl*), of which the shape of the instrument is reminiscent.[127] This text is probably not by al-Khwārizmī but could nevertheless stem from an Abbasid author. The obliquity of the ecliptic $\epsilon = 23°33'$ underlying the accompanying table, associated with the Mumtaḥan observations, suggests a date after *ca.* 830 AD.[128]

Whereas the description of the sundial as well as its depiction on f. 192v confirm its conical shape, the instructions of its construction and the accompanying numerical table rather suggest that it is cylinder. If we assume that it is conical, then we can also rely on the descriptions of such dials by later authors such as al-Marrākushī or Yaḥyā al-Ṣiqillī.[129] It consists of two parts: a vertical truncated cone and a hemispheric head that bears a movable gnomon. The head of the cone measures five sixths of its base. The circumferences of the head and base are divided into six sections, which means that the lines, and not the spaces between them, represent zodiacal signs of equal, which is more clearly stated at the end of the text.[130] The cone bears a shadow scale along its side, its length being divided into 30 equal parts. The shadow lengths for the six unequal hours are taken from a table and marked by means of a compass. The length of the projecting part of the gnomon is five parts. It is fixed with the hemispheric head that rotates over the truncated cone. For time

[127] On the etymology of the word see further Wiedemann & Würschmidt (1916: 359–360); on its history see Livingston (1972: 299–300). According to Forcada (1990: 66), its first occurence in Andalusi sources is in a text by al-Umawī al-Qurṭubī (Cordova, b. 1120/21).

[128] This value was first determined by Yaḥyā ibn Abī Manṣūr in 213 H [828/29 AD]. See Bīrūnī (1962: 89–90).

[129] See Livingston (1972), Würschmidt & Wiedemann (1916), Sédillot (1834: 450) and Charette (2003: 150–153).

[130] The figure on $\mathcal{A}$:192v is unreliable: it shows seven divisions, but the outer lines are not used, and the remaining ones are incorrectly labelled in pairs, as in the table on f. 191v. We have reproduced it in the edition exactly as it appears in the manuscript.

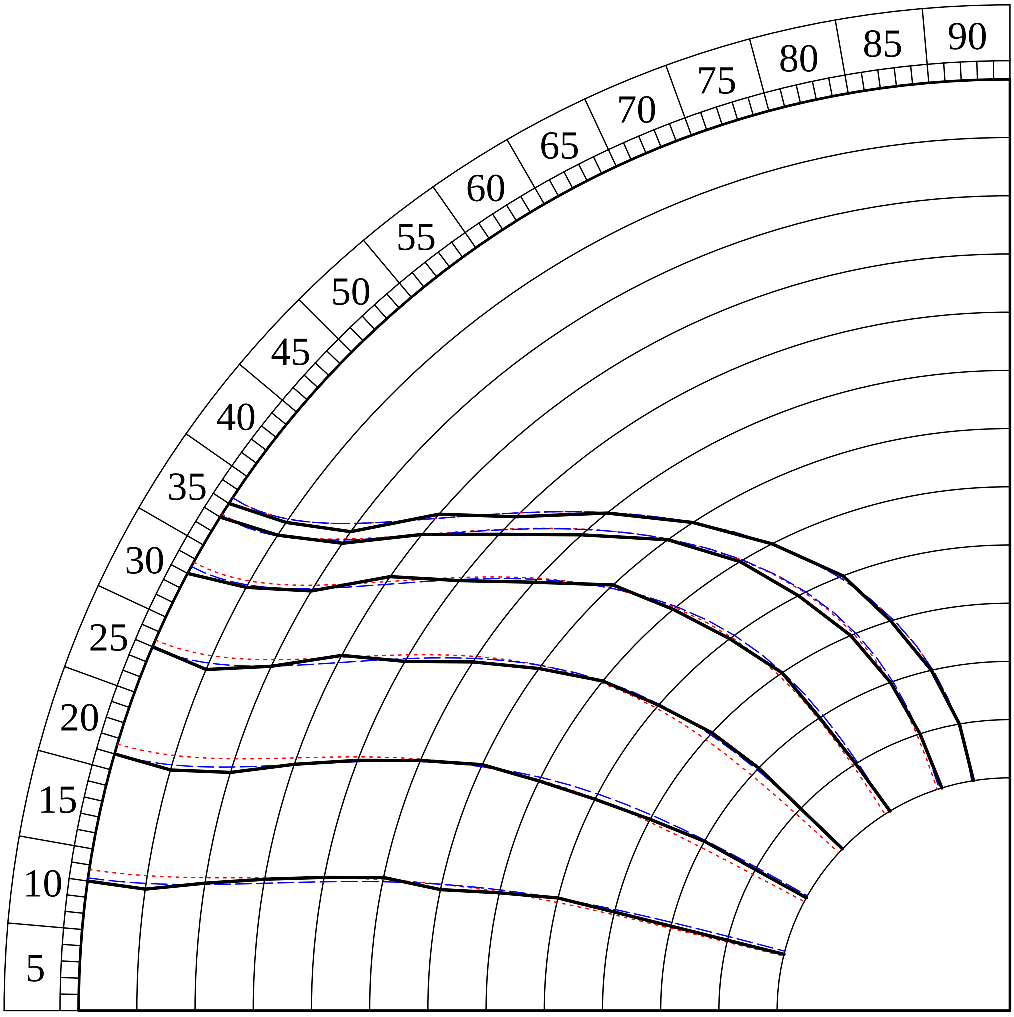

Figure 7: A reconstruction of the horary quadrant for the latitude of Baghdad described in Text 10. The dark lines are based on the table provided in the text (using linear joints between each dot). The dashed and dotted lines are accurate representations of the hour-lines based on the approximate formula advocated in the text and on the accurate formula, respectively.

reckoning the dial has to be suspended and turned towards the sun, the gnomon has to be rotated vis-à-vis the appropriate sign, and the time in unequal hours can be read by visual interpolation of the tip of the shadow between the hour-lines.

Conical sundials are closely linked to cylindrical dials, also known as shepard's dials, which are constructed and used in a similar way.[131] But the *mukḥula* has

[131] See Wiedemann & Würschmidt (1916: 373ff) and Livingston (1972: 303); for a Roman cylindrical sundial, see Arnaldi & Schaldach (1997); for later European cylindrical dials, see for example

the advantage that if the sun is very high or even in the zenith, it may be possible that its shadow will fall on the surface of the cone. The hours around midday are more distinct on a conical sundial than on a cylindrical sundial, where the markings around midday are very close to each other. This may be of special importance for the midday prayer. Further a conical sundial could be smaller than a cylindrical sundial and still achieve the same purpose with the same precision.

It is not totally clear which sort of a sundial the table on $\mathcal{A}$:192r serves. It seems to agree rather well with a recomputation for a *cylindrical* sundial for the latitude $\phi = 33°$ (Baghdad), an obliquity $\epsilon = 23°33'$ and a gnomon length of five parts – which is an uncommon parameter[132] – but the errors are not insignificant (see p. 159). Of course, it is well possible to use a table of vertical shadow lengths to construct the hour curves on a conical sundial by means of ruler and compass, so we cannot exclude that the table was indeed intended to construct the instrument described in the text.

Glasemann (1999: 42f); Michel (1974: 16f); Turner (1991: 146) or Willers (1992: 616).

[132] On base five for shadow functions, see King (2004: 25).

V Appendices

Appendix 1: Marginal glosses on the use of the astrolabe — $\mathcal{B}$: 82r–83r

[NB: these glosses are posterior to the wormholes and to the Arabic foliation – the handwriting may be 17th or 18th century, whilst the text of the glosses might be from a Mamluk source.]

[1] إذا أردنا معرفة ما مضى من النهار من ساعة معوجّة : وضعنا جزء الشمس على مثل ارتفاعها في المقنطرات في الجهة التي هو فيها من المشرق أو المغرب على صفيحة عرض بلدنا ونظرنا إلى نظير جزء الشمس وهو مثل درجتها من البرج السابع كم يقع تحت الأفق من الساعات فما كان فهو الماضي من النهار في ذلك الوقت

[2] وإذا أردنا معرفة ما مضى من اللّيل من ساعة معوجّة : عرفنا ارتفاع أحد الكواكب المرسومة في العنكبوت ووضعنا مري ذلك الكوكب على مثل ارتفاعه في المقنطرات في الجهة التي هو فيها ونظر جزء الشمس كم يقع تحت الأفق من الساعات المعوجّة فما كان فهو الماضي من اللّيل

[3] معرفة[1] تعديل الساعات المعوجّة إذا وقع نظير جزء الشمس بالنهار أو جزء الشمس باللّيل بين ساعتين فالماضي ساعات وكسر : فإن أردنا معرفة ... (؟)[2] علّمنا على موقع المري من أجزاء الحجرة ورددنا نظير جزء الشمس بالنهار أو جزء الشمس باللّيل إلى الساعة التي جاوزها وننظر كم زال المري عن موضعه[3] فما كان فهو أجزاء الكسر فنعلّم على موقع المري فهذا (؟) الثاني وندير العنكبوت على توالي البروج حتّى نضع جزء الشمس أو نظيره على الساعة التي هو صائر (؟) إليها وننظر كم زال المري عن موضعه الثاني فنحفظه ونضرب أجزاء (؟) الكسر في ٦٠ ونقسم ما بلغ على ما حفظنا فما خرج فهو دقائق الكسر من ساعة معوجّة

[4] معرفة الدائر باللّيل منذ غابت الشمس : إذا أردنا ذلك عرفنا ارتفاع أحد الكواكب الثابتة المرسومة في العنكبوت ووضعنا مري ذلك الكوكب على مثل ارتفاعه في المقنطرات في جهته وعلّمنا على موقع المري[4] من أجزاء الحجرة وأدرنا العنكبوت إلى خلاف التوالي حتّى يردّ (؟) جزء الشمس إلى مقنطرة المغرب[5] فما زال المري عن موضعه من أجزاء الحجرة فهو الدائر من مغيب الشمس إلى وقت الركند (؟)

[5] ⟨82v⟩ معرفة قوس نهار الشمس أو الكوكب : إذا أردنا ذلك وضعنا جزء الشمس أو مري الكوكب على أفق المشرق في صفيحة البلد الذي نريد وعلّمنا على موقع المري من أجزاء الحجرة وأدرنا العنكبوت على توالي البروج حتّى نضع جزء الشمس أو مري الكوكب على أفق المغرب وننظر كم زال المري عن موضعه فما كان فهو قوس النهار في ذلك اليوم أو قوس نهار ذلك الكوكب

[6] معرفة ما دار من الفلك منذ طلعت الشمس أو الكوكب : إذا أردنا ذلك عرفنا ارتفاع الشمس أو الكوكب ثمّ وضعنا جزء الشمس أو مري الكوكب على مثل ارتفاعه في المقنطرات في جهته من المشرق أو المغرب في صفيحة

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[1] *bis* MS

[2] Illeg. MS. Perhaps كم وقع ?

[3] موضعه illeg. MS

[4] المري hidden on microfilm

[5] المغرب hidden on microfilm

بلدنا وعلّمنا على موقع المري من أجزاء الحجرة وأدرنا العنكبوت على غير توالي البروج حتّى نضع جزء الشمس أو مري الكوكب على مقنطرة مقنطرة المشرق وننظر كم زال المري عن موضعه من أجزاء الحجرة فما كان فهو ما دار من الفلك منذ طلوع الشمس أو الكوكب فإن قسمناه على يب خرجت ساعات مستوية مضت من طلوع الشمس أو الكوكب وإن أدرنا العنكبوت على توالي البروج حتّى نزد (؟) جزء الشمس أو مري الكوكب من مثل ارتفاعه إلى أفق المغرب كان ما زال المري من أجزاء الحجرة هو الباقي إلى أن تغرب الشمس أو الكوكب

[7] معرفة قوس اللّيل : نضع جزء الشمس أو مري الكوكب على أفق المغرب ونعلّم على موقع المري ثمّ ندير العنكبوت إلى توالي البروج حتّى نضع جزء الشمس أو مري الكوكب على أفق المشرق وننظر كم زال المري عن موضعه فما كان دهو قوس اللّيل في اللّيلة التي أردنا أو قوس ليلة ذلك الكوكب الثابت فإن أردنا نصف القوس أدرنا الجزء أو مري الكوكب من أفق المشرق إلى خطّ نصف النهار، أو من [خطّ] المغرب إلى خطّ وتد الأرض، فما زال المري عن موضعه فهو نصف تلك القوس التي أردنا

[8] ⟨83r⟩ معرفة أجزاء ساعات اللّيل والنهار : نضع نظير جزء الشمس بالنهار أو جزء الشمس باللّيل على مقنطرة المغرب وعلّمنا على موقع المري من الحجرة ثمّ أدرنا العنكبوت على توالي البروج حتّى نضع الجزء أو النظير على خطّ ساعة واحدة من الساعات المعوجّة وننظر كم زال المري فما كان فهو أجزاء ساعات ذلك اليوم إن عملنا بنظير جزء الشمس، أو أجزاء ساعات اللّيل إن عملنا بجزء الشمس. وإن قسمنا قوس اللّيل أو النهار على يب خرجت أجزاء الساعات ، أو على يه خرجت الساعات المستوية في ذلك اليوم أو تلك اللّيلة.

[9] معرفة الطالع والأوتاد : نعرف ارتفاع الشمس أو أيّ كوكب أردنا من المرسومة في العنكبوت ثمّ نضع جزء الشمس أو مري الكوكب على مثل ارتفاعه في المقنطرات في جهته من المشرق أو المغرب في صفيحة بلدنا فما قطع مقنطرة المشرق من أجزاء البروج فهو الطالع وما قطع مقنطرة المغرب فهو السابع وما قطع خطّ نصف النهار فهو { خطّ نصف النهار فهو } العاشر وما قطع خطّ وتد الأرض فهو الرابع وينبغي أن يكون الرابع نظير العاشر والسابع نظير الطالع فإن كان ذلك فصحيح وإلّا فالأصطرلاب زائل.

Appendix 2: Various tables found in $\mathcal{B}$: 93v, 94v–95v

A table of the right ascension for each 3° of longitude

⟨93v⟩

جدول مطالع الفلك المستقيم لكل ثلاث بروج معمول			
العدد	مطالع الجدي في الفلك المستقيم	مطالع الدلو في الفلك المستقيم	مطالع الحوت في الفلك المستقيم
ج	ج يو و	له يح نا	سد نز مط
و	و لب يو	لح كد ٠	سز مز مط
ط	ط مح [a] د	ما كز كا	ع لو مح
يب	يج ج يز	مد كط ط	عج كد مح
يه	يو يز مب	مز كط يح	عو يا ند
يح	يط ل نه	ن كز مز	عح نح كه
كا	كب مج يب	نج كد مه	فا مد يح
كد	كه ند يح	نو ك ط	فد كط مح
كز	كط جمح	نط ك [b] ٠	فز يه [c] يح
ل	لب يب ط	سب و لد	ص ٠ ٠

[a] مج MS [b] This is erroneous (recomputation is 59;14,25). [c] نه MS

A table of the solar altitude at each seasonal hour for latitudes 25° to 90°

⟨94v⟩ **[جدول] ارتفاع نصف النهار من كه إلى ص وارتفاع الساعات**

العدد	الساعة الأولة	الثانية	الثالثة	الرابعة	الخامسة	السادسة
كه	ز	يب	يز	كب	كد	كه
كو	ز	يج	يح	كج	كه	كو
كز	ز	يج	يط	كج	كو	كز
كح	ز	يد	ك	كد	كز	كح
كط	ز	يد	كا	كه	كح	كط
ل	ز	يد	كا	كو	كط	ل
لا	ح	يه	كب	كز	ل	لا
لب	ح	يه	كب	كز	لا	لب
لج	ح	يو	كج	كح	لب	لج
لد	ح	يو	كج	كح	لج	لد
له	ح	يز	كد	كط	لد	له
لو	ح	يز	كد	ل	له	لو
لز	ط	يح	كه	لا	لو	لز
لح	ط	يح	كو	لب	لو	لح
لط	ط	يح	كز	لج	لز	لط
م	ط	يط	كز	لد	لح	م
ما	ي	يط	كح	له	لط	ما
مب	ي	ك	كح	لو	م	مب
مج	ي	ك	كط	لز	ما	مج
مد	ي	ك	كط	لح	مب	مد
مه	يا	كا	ل	لط	مج	مه
مو	يا	كا	لا	م	مد	مو
مز	يا	كا	لا	م	مه	مز
مح	يا	كب	لب	ما	مو	مح
مط	يا	كب	لب	مب	مز	مط
ن	يب	كب	لب	مب	مح	ن
نا	يب	كج	لج	مب	مط	نا
نب	يب	كج	لج	مج	ن	نب
نج	يب	كج	لد	مد	نا	نج
ند	يب	كج	لد	مد	نب	ند
نه	يب	كد	له	مه	نج	نه
نو	يب	كد	لو	مو	ند	نو
نز	يج	كه	لز	مز	نه	نز [a]

العدد	الاولة	الثانية	الثالثة	الرابعة	الخامسة	السادسة
نح	يج	كه	لز	مح	نه	نح
نط	يج	كه	لز	مح	نو	نط
س	يج	كو	لح	مط	نز	س
سا	يج	كو	لح	ن	نح	سا
سب	يج	كو	لح	ن	نط	سب
سج	يج	كو	لط	نا	نط	سج
سد	يج	كز	لط	نا	س	سد
سه	يد	كز	لط	نب	سا	سه
سو	يد	كز	م	نب	سب	سو
سز	يد	كز	م	نج	سج	سز
سح	يد	كح	ما	نج	سد	سح
سط	يد	كح	ما	ند	سد	سط
ع	يد	كح	مب	ند	سه	ع
عا	يد	كح	مب	نه	سو	عا
عب	يد	كح	مب	نو	سز	عب
عج	يد	كط	مج	نو	سح	عج
عد	يد	كط	مج	نز	سط	عد [b]
عه	يد	كط	مج	نز	ع	عه [b]
عو	يه	كط	مج	نح	عا	عو [b]
عز	يه	كط	مج	نح	عب	عز [c]
عح	يه	ل	مد	نح	عج	عح
عط	يه	ل	مد	نح	عج	عط
ف	يه	ل	مد	نح	عج	ف
فا	يه	ل	مد	نح	عج	فا
فب	يه	ل	مد	نط	عد	فب
فج	يه	ل	مد	نط	عد	فج
فد	يه	ل	مد	نط	عد	فد
فه	يه	ل	مه	نط	[عد] [d]	[فه] [d]
فو	يه	ل	مه	نط	[عد] [d]	[فو] [d]
فز	يه	ل	مه	س	عد	فز
فح	يه	ل	مه	س	عه	فح
فط	يه	ل	مه	س	عه	فط
ص	يه	ل	مه	س	عه	ص

[a] Original entry deleted and نح written in another handwriting. [b] Entry partly illegible (wormhole) and restored in the margin (handwriting of al-Ṭūlūnī?). [c] Entry عو emended in the margin (handwriting of al-Ṭūlūnī?). [d] Wormhole.

A table of the 'sine of the hours' for latitudes 25° to 90°

⟨95r⟩ **جدول جيب الساعات لارتفاع نصف النهار من كه إلى ٩٠**

الارتفاع	ساعة اولة		ساعتين		ثلث ساعات		اربع ساعات		خمس ساعات		ست ساعات	
	دقائق	ثواني	دقائق	ثواني	دقائق	ثواني	دقائق	ثواني	دقائق	ثواني	دقائق	ثواني
٢٥	١٦	٢٩	١٥	١٣	١٣	٦	١٠	٩	٦	٢٠	٢	٦
٢٦	١٧	٦	١٥	*١٧	١٣	٣٥	١٠	٣١	٦	٣٤	٢	١١
٢٧	١٧	٢٦	١٦	٦	١٣	٥٢	١٠	٤٤	٦	٤٢	٢	١٤
كح	١٨	١٨	١٦	٥٤	١٤	٣٣	١١	١٦	٧	٢	٢	٢١
كط	١٨	٥٤	١٧	٢٧	١٥	١	١١	٣٧	٧	١٦	٢	٢٥
ل	١٩	٣٠	١٨	٠	١٥	٣٠	١٢	٠	٧	٣٠	٢	٣٠
لا	٢٠	٤	١٨	٣١	١٥	٥٧	١٢	٢٠	٧	*٣٤	٢	٣٤
لب	٢٠	٣٨	١٩	٢	١٦	٢٤	١٢	٤٢	٧	٥٦	٢	٣٨
لج	٢١	١١	١٩	٣٣	١٦	٥٠	١٣	٢	٨	٩	٢	٤٣
لد	٢١	٤٥	٢٠	٤	١٧	١٧	١٣	٢٣	٨	٢٢	٢	٤٧
له	٢٢	١٨	٢٠	٣٥	١٧	٤٣	١٣	٤٣	٨	٣٤	٢	٥٢
لو	٢٢	٥٠	٢١	٥	١٨	٩	١٤	٣	٨	٤٧	٢	٥٦
لز	٢٣	٢٣	٢١	٣٥	١٨	٣٥	١٤	٢٣	٩	٠	٣	٠
لح	٢٣	٥٥	٢٢	٥	١٩	١	١٤	٤٣	٩	١٢	٣	٤
لط	٢٤	*[•]٧	٢٢	٣٤	١٩	٢٦	١٥	٢	٩	٢٤	٣	٨
م	٢٤	٥٩	٢٣	٣	١٩	٥١	١٥	٢٢	٩	٣٦	٣	١٢
ما	٢٥	٣٠	٢٣	٣٢	٢٠	١٦	١٥	٤٢	٩	٤٨	٣	١٦
مب	٢٦	١	٢٤	١	٢٠	٤١	١٦	١	١٠	٠	٣	٢٠
مج	٢[٦]	٣٢	٢٤	٣٠	٢١	٥	١٦	٢٠	١٠	١٢	٣	٢٤
مد	٢٧	٣	٢٤	٥٨	٢١	*٤٠	١٦	٣٩	١٠	٢٤	٣	٢٨
مه	٢٧	٣٣	٢٥	٢٦	٢١	٥٤	١٦	٥٧	١٠	٣٦	٣	٣٢
مو	٢٨	٠	٢٥	٥١	٢٢	١٥	١٧	١٤	١٠	٤٦	٣	٣٥
مز	٢٨	٢٧	٢٦	١٥	٢٢	٣٧	١٧	٣٠	١٠	٥٦	٣	*٣٠
مح	٢٨	٥٣	٢٦	٤٠	٢٢	٥٧	١٧	٤٦	١١	٦	٣	٤٢
مط	٢٩	١٩	٢٧	٤	٢٣	١٨	١٨	٢	١١	١٦	٣	٤٥
ن	٢٩	٤٤	٢٧	٢٤	٢٣	٣٩	١٨	١٨	١١	٢٦	٣	٤٨
نا	٣٠	١٠	٢٧	٥١	٢٣	٥٩	١٨	٣٤	١١	٣٦	٣	٥٢
نب	[٣٠]	٣٥	٢٨	١٤	٢٤	١٩	١٨	٤٨	١١	٤٦	٣	٥٥
نج	[٣١]	٠	٢٨	٣٧	٢٤	٣٩	١٩	٥	١١	٥٥	٣	١٨
ند	[٣١]	*[•]٢	٢٩	٠	٢٤	٥٨	١٩	٢٠	١٢	٥	٤	١
نه	٣١	٥٠	٢٩	٢٢	٢٥	١٨	١٩	٣٥	١٢	١٦	٤	٥
نو	٣٢	١٩	٢٩	٤٥	٢٥	٣٧	١٩	٥٠	١٢	٢٦	٤	٨
نز	لب	*يح	د	ند	كه	نو	ك	ه	يب	†*مح	†د	†يا

Remarks: This table has been analyzed in Hogendijk (1991). In this edition we have performed obvious restorations only. An asterisk means that a reconstructed or emended entry is given in Hogendijk (1991).

† These entries are repeated (likewise in *abjad* notation) in the first line, last three columns of the following table on f. 95v (argument 58) and the rest of the entries are consequently displaced.

⟨95v⟩

جدول جيب الساعات لارتفاع نصف النهار من كه إلى ٩٠ مقطع

ساعة سادسة		ساعة خامسة		ساعة رابعة		ساعة ثالثة		ساعة ثانية		ساعة اولة		العدد
ثواني	دقائق	ثواني	دقائق	ثواني	دقائق	ثواني	دقائق	ثواني	دقائق	ثواني	دقائق	
يد	د	نب*	يب	يه*	ك	يه	كو	كط	ل	١ [a]	٣٣	نح
يز	د	نا	يب	لج	ك	لج	كو	ز	ل	٢٥	٣٣	نط
ك	د	٠	يج	مح	ك	نب	كو	يب	لا	٤٨	٣٣	س
لب	د	و	يج	نط [c]	ك	و	كز	كح	لا	٥	٣٤	سا
كد	د	يج	يج	ط	كا	مط	كز	مد	لا	٢٢	٣٤	سب
كو	د	ك	يج	ك	كا	لج	كز	نط	لا	٣٩	٣٤	سج
كط	د	كو	يج	ل	كا	مو	كز	يد	لب	٥٧	٣٤	سد
لا	د	لب	يج	م	كا	نط	كز	ل	لب	١٢	٣٥	سه
لج	د	لط	يج	ن	كا	يب	كح	مد	لب	٢٨	٣٥	سو
له	د	مه	يج	٠	كب	كد	كح	نط	لب	٤٤	٣٥	سز
لز	د	نا	يج	ط	كب	لز	كح	يد	لج	٠	٣٦	سح
لط	د	نو	يج	يط	كب	مط	كح	كج*	لج	١٥	٣٦	سط
ما	د	ب	يد	كح	كب	ي*	كط	مب	لج	٣٠	٣٦	ع
مج	د	ح	يد	لز	كب	يج	كط	نو	لج	٤٥	٣٦	عا
مد	د	يد	يد	مو	كب	كد	كط	ط	لد [b]	٠	٣٧	عب
مو	د	يط	يد	نه	كب	لو	كط	كب	لد	١٤	٣٧	عج
مح	د	كه	يد	ج	كج	مز	كط	له	لد	٢٨	٣٧	عد
ن	د	ل	يد	يب	كج	نح	كط	مح	لد	٤٢	٣٧	عه
نا	د	لج	يد	يو	كج	ج	ل	ند	لد	٤٩	٣٧	عو
نب	د	له	يد	ك	كج	ط	ل	ا	له	٥٦	٣٧	عز
نب	د	لح	يد	كد	كج	يد	ل	ز	له	٠	٣٨	عح
نج	د	م	يد	كح	كج	يط	ل	يب	له	٨	٣٨	عط
ند	د	مب	يد	لب	كج	كد	ل	يح	له	١٤	٣٨	ف
نه	د	مه	يد	له	كج	كج	ل	كج	له	٢٠	٣٨	فا
نه	د	مز	يد	لط	كج	لج	ل	كح	له	٢٦	٣٨	فب
نو	د	مط	يد	مب	كج	لز	ل	لج	له	٣١	٣٨	فج
نز	[د]	نا	يد	مد	كج	ما	ل	لز	له	٣٦	٣٨	فد
نز	[د]	نب	يد	مح	كج	مد	ل	مب	له	٤٠	٣٨	فه
نح	[د]	ند	يد	نا	كج	مح	ل	مو	له	٤٤	٣٨	فو
نح	د	نو	يد	نح*	كج	نا	ل	ن	له	٤٩	٣٨	فز
نط	د	نز	يد	نو	كج	ند	ل	نج	له	٥٣	٣٨	فح
نط	د	نط	يد	نح	كج	نز	ل	نز	له	٥٦	٣٨	فط
٠	[d] [ه]	٠	يه	٠	كد	٠	لا	٠	لو	٠	٣٩	ص

[a] ٠١ (!) Ms. [b] لحـ Ms. [c] نط Ms. [d] In this column the entry د is written once in each cell, serving three entries at once. But since the last cell serves four entries (because of the displacement), the entry for argument 90 has been omitted.

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