A Universal Plate for Timekeeping by the Stars by Ḥabash al-Ḥāsib: Text, Translation and Preliminary Commentary

François Charette and Petra G. Schmidl

1 Introduction

Most publications of texts by historians of ancient and medieval exact science demand (1) a mastery of the primary sources coupled with (2) an ability to provide a technical interpretation within (3) an acceptable historical perspective. The authors of the present paper, while hoping to have satisfied the first and third criteria, have to admit their present inability to fulfil the second one adequately. In this paper we present an Arabic treatise on the construction of a 'universal plate' for timekeeping by the stars. No such instrument is known from Islamic or European sources.[1]

[1] 'Universal plates' in Islamic sources usually correspond to one of the following three devices: (1) the 'plate of horizons' (*al-ṣafīḥa al-āfāqiyya*) or its generalization by Ibn Bāṣo, (2) the universal stereographic projection on the front of the plates known as the *shakkāziyya* and the *zarqālliyya* or on the mater of the universal astrolabe, and (3) the orthogonal projection on the back of the *zarqālliyya*. In a paper by Prof. Paul Kunitzsch (1994, p. 85), there is a reference to a treatise in a manuscript in the collection of Khan Malik Sasani in Iran, entitled *Kitāb fī ʿAmal musaṭṭaḥ yaqūmu maqāmā al-asṭurlāb* [*fī*] *jamīʿ al-ʿurūḍ wa-l-buldān* ('Book on the construction of a planisphere which takes the place of the astrolabe [in] all latitudes and places'). It would be very interesting to know which kind of instrument this refers to, but unfortunately the manuscript is not accessible to us.

The treatise is anonymous but we can attribute it with confidence to the renowned ninth-century Abbasid astronomer Ḥabash al-Ḥāsib. This instrument of his is a computing device of great ingenuity. Although our understanding of several details of its construction is not satisfactory, the text and the accompanying illustrations give us a more or less limpid picture of its morphology. Unfortunately, not a single word of the text is devoted to its use, and we have not yet been able stretch our imaginations far enough to 'crack' this problem. We therefore submit Ḥabash's text to colleagues in the hope that some of them might help us to see more light about how this ninth-century scientist might have conceived the practical operation of his invention.

The unique copy of the text which is the object of the present study is found in an important manuscript in Oxford (Bodleian Marsh 663) containing an impressive collection of scientific texts, most of them from the early period of Islamic science, which was copied between Rajab 639 H and Muḥarram 640 H by Ibrāhīm b. ʿAbd al-ʿAzīz b. ʿAbd Allāh al-ʿUmarī.[2] A second manuscript in London (British Library Or. 426 = Add. 7473, dated 639 H) originally formed together with the Oxford manuscript a single book, which was later split in two halves.[3] Yet a third manuscript in the Süleymaniye Library in Istanbul (Yeni Cami 784), containing (1) the *Pentateuch* of Dorotheos, (2) the *Zīj* of Ḥabash al-Ḥāsib,[4] (3) *al-Zīj al-Jāmiʿ* of

2 On this manuscript see the lacunary description by Uri (1787), *sub* no. CMXLI. Studies based on various parts of this collection include: Rosenthal (1950), Rosenthal (1949), Pingree (1968), p. 63, Kennedy (1968), Kennedy (1990) and Burnett & Yamamoto & Yano (1997). Both authors of the present paper could examine this manuscript at the Bodleian Library in July 1997. We are grateful to Dr. Colin Wakefield for his generously giving us access to it and providing photographs of the section dealing with Ḥabash's instrument.

3 On the contents see *CCMO*, *sub* no. 426. Taken together the Oxford and London manuscripts encompass 379 folios, but the original foliation in Coptic numerals shows us that the original *majmūʿa* was an impressive book of at least 516 folios! The first author of this paper has prepared a description of the two manuscripts for future publication.

4 On this work see Debarnot (1987).

Kūshyār b. Labbān, as well as (4) Kūshyār's treatise on the astrolabe, reveals the same characteristic handwriting and paleographical peculiarities as the two above-mentioned manuscripts and was clearly also copied by Ibrāhīm al-ʿUmarī.[5]

On p. 205 of the Oxford manuscript an anonymous and untitled treatise begins with the words "if we want to construct the plate, we make the universal plate … ". Since a few folios of the codex have been bound in disorder, the text beginning on pp. 205–206 actually continues on pp. 239–247. In the upper margin of p. 205 a later reader has given this treatise a short title: *fī al-ṣafīḥa al-jāmiʿa* ('on the universal plate'). In the last sentence of the text on p. 247, however, what was presumably the original title of the treatise is mentioned more precisely as *fī ʿamal al-ṣafīḥa al-jāmiʿa* ('on the construction of the universal plate'). The possible significance of this treatise was already recognized by Fuat Sezgin in the sixth volume of his *Geschichte des arabischen Schrifttums*.[6] Some three decades earlier, Franz Rosenthal had already tentatively attempted to identify this treatise with al-Kindī's *R. fī al-ʿAmal bi-l-āla al-musammā al-jāmiʿa* ('Treatise on the Use of the Instrument Called the Universal One').[7] This supposition has been repeated with caution by Charles Burnett, Keiji Yamamoto and Michio Yano in a recent paper.[8]

A preliminary investigation of this work was conducted by us in the Spring of 1997 as part of a seminar on Arabic scientific texts given by Prof. David King at Frankfurt University.[9] It was soon realized that Ḥabash al-

5 This confirms the dating of this manuscript by Krause (1938) and Sezgin (1978) to the thirteenth century.

6 Sezgin (1978), p. 281 under the heading 'Ein Anonymus': "Die *Risāla* […], über das Planisphärium [*sic*], steht auf einem hohen Niveau astronomischer Mathematik."

7 Rosenthal (1949), p. 150; a treatise with this title is attributed to al-Kindī by Ibn Abī Uṣaybiʿa. If the 'philosopher of the Arabs' was indeed the author of a work with this title, then it would concern the *use* of some universal instrument (not necessarily a 'plate'). Hence it cannot be identical with the text extant in manuscript Marsh 663.

8 Burnett, Yamamoto & Yano (1997), pp. 61–62, esp. n. 12.

9 The treatise had also been studied by King and Dorothea Girke seven or eight years

Ḥāsib was a serious candidate for author. The first reason for our suspicion was mainly the particular value of the latitude given in one of the worked examples, as well as the star coordinates given in the tables. We shall now discuss these points further and present more evidence for our attribution.

1.1 The attribution to Ḥabash

There are four decisive arguments in support of our attribution:

1. The latitude 34° (intended for Samarra, the Abbasid capital from 221/836 until 279/892) is used in a worked example (p. 240 of the manuscript; see our edition below): the use of this latitude is peculiar to many of Ḥabash's writings. In his *Zīj* all of his worked examples as well as the star table mention the name of, or employ the latitude of Samarra,[10] and likewise in his treatise on the melon astrolabe.[11]

   David King has recently argued that the treatise on sundials attributed to al-Khwārizmī might actually be by Ḥabash, firstly because in Ibn al-Nadīm's bibliography such works are indeed associated to the former and not to the latter, and secondly because "the most elaborate tables in the set are for latitude 34°".[12] It is not known whether al-Khwārizmī was ever associated with the Abbasid court at Samarra, although it is true that we know very little about his life.[13] The only

before us. In 1997, however, we began from scratch.

10 See Debarnot (1987).

11 Kennedy, Kunitzsch & Lorch (1999). Two other works by Ḥabash have been published, one dealing with the use of the spherical astrolabe (see Kunitzsch and Lorch (1985)), and another one entitled *On the Sizes and Distances*, which in fact discusses various topics relating to the achievements of the group of scientists who worked for al-Ma'mūn; it was probably written in Baghdād shortly after the caliph's death — see Langermann (1985) and King (2000). Rida A.K. Irani's M.A. thesis entitled "The *Jadwal al-taqwīm* of Ḥabash al-Ḥāsib", (American University of Beirut, 1956) has unfortunately never been published.

12 King (1999), p. 350.

13 But the same remark also applies to Ḥabash!

astronomers apart from Ḥabash who can be securely associated with Samarra were in fact the Banū Mūsā and al-Māhānī.[14] We do not know to what extent they might have collaborated with him, but it appears that Ḥabash adopted several parameters based on their respective observations.[15]

2. The star table encountered in the work under discussion was directly taken from Ḥabash's version of the *Mumtaḥan* star table in his *Zīj*;[16] furthermore some star coordinates not found in the latter source are confirmed in Ḥabash's treatise on the melon astrolabe.[17]

3. In a worked example, values are given for the Sines of 34° and 56°, and these again correspond exactly with the respective entries of Ḥabash's Sine table.[18]

14 See Sayılı (1960), pp. 92–94. al-Bīrūnī and Ibn Yūnus report several observations made by the Banū Mūsā in Samarra. It is curious that Ḥabash's association with this city is never mentioned in the standard biographical articles, such as Hartner (1971) and Tekeli (1972), or even in Sayılı's essay on Islamic observatories cited above. The first mention is in fact in Debarnot (1987).

15 In his *Qānūn*, al-Bīrūnī states that in general, Ḥabash's parameters derive from the observations of the Banū Mūsā (Debarnot (1987), p. 43). At one place in his *Zīj*, Ḥabash gives an example for latitude 34;12° (instead of the rounded value 34° which he usually employs). 34;12° is precisely the latitude of Samarra which is recorded by al-Bīrūnī in his *Qānūn* (Kennedy & Kennedy, 1987) and also in his *Taḥdīd* (al-Bīrūnī, pp. 85, 212–213). al-Bīrūnī does not ascribe the determination of this value to anybody in particular, but says that it was due to "other observations [than those of the Banū Mūsā he quoted]" (p. 85), and also that it was accepted by the majority (p. 213). In fact, we learn from Ibn Yūnus (MS Leiden Or. 143 [= 1057], p. 223) that it was al-Māhānī who found it on the basis of observations conducted in Samarra in 243 H (= 857 A.D.). This measurement is remarkable since it is only one minute different than the modern value for Samarra (34° 13′) given in Kennedy & Kennedy (1987).

16 See note 113 on p. 139 for reference to the sources.

17 E.g. the declination of *fam al-samaka* (see Table 3, note *l*, on p. 143) and the mediation and declination of *suhayl* (see Table 4, note *c*, on p. 144 and note *m* to the table on p. 146).

18 See n. 119 on p. 150.

4. Two different values of the obliquity can be detected in this work, namely 23;35° and 23;33°. The former parameter underlies a list of right ascensions given in the text (see p. 151 below) and the latter is explicitly visible on the declination scale featured in Figure 6 (analysed on p. 154). It is well known that Ḥabash used the value 23;35 in his *Zīj*[19] and in the treatise on the melon astrolabe.[20] In the first version of his *Jadwal al-taqwīm*, however, Ḥabash had rather employed 23;33°.[21] The parallel use by Ḥabash of these two different values of the obliquity is confimed by Ibn Yūnus.[22]

5. Finally, the style and technical terminology of the treatise on the universal plate are very close to those encountered in the treatise on the melon astrolabe. Four examples might suffice to illustrate this claim:

   (a) On some geometrical diagrams, numbers in *abjad* notation are used as 'diagram letters' designating specific points of a numerical scale associated with those numbers. For example a point associated with a longitude of 12 degrees measured from point *A* will be denoted *A*-12 (ا يب). Compare Section [5] of the present treatise with f. 147r:8–24 of Ḥabash's treatise on the melon astrolabe (Kennedy, Kunitzsch & Lorch, pp. 64–67). Incidentally, the respective sections of both works turn out to be very similar; see further our commentary on Section [7]. This method of lettering is a unique and extremely interesting example of a fully neglected aspect of Islamic scientific practice, namely the techniques employed to convey non-verbal information by means

19 Debarnot (1987), p. 47.

20 Kennedy, Kunitzsch & Lorch (1999), pp. 97, 102.

21 Debarnot (1987), pp. 48, 62. This value is reported to have been determined in 213 H by Yaḥyā b. Abī Manṣūr; see al-Bīrūnī, pp. 89–91.

22 MS Leiden Or. 143, p. 223.

of diagrams, graphs, tables, etc.[23] The procedure of combining letters and numerals for marking elements of a mathematical diagram is apparently first attested in Europe in some works by Leibniz.[24]

(b) The peculiar use, in both treatises, of the word *majrā* (instead of *madār*) in the expression *mayl majrā al-kawākib ʿan muʿaddil al-nahār*, to designate the declination of fixed stars. Compare Sections [2] and [3] and Table 3 of our edition with f. 141r:7–8 and Table 3 of the treatise on the melon astrolabe (pp. 18 and 88 of the edition, respectively).

(c) The expression *ka-hay'at* ... ('in the form of, such as [some geometrical element]') in reference to a geometrical diagram. Compare the first sentence of our edition with the treatise on the melon astrolabe (f. 141r:8, p. 18 of the edition).

(d) The common structure of Sections [2] and [3] of our treatise and of the various problems presented in the first half of the treatise on the melon astrolabe, which consists of first presenting a graphical solution to a given problem, then its equivalent trigonometric formula and finally a worked example.

More details concerning the points evoked in items 2 and 3 will be given in our commentary. Another argument in favour of Ḥabash is the fact that three short sections extracted from his *Zīj* – and explicitly attributed to him – do appear in the Oxford manuscript:

1. *Min Zīj Ḥabash fī maʿrifat masīr al-shams wa-l-qamar al-muṣaḥḥaḥ* (pp. 55–56): identical with the section of Ḥabash's *Zīj* in MS Istanbul Yeni Cami 784/2, f. 151v:11–22.

2. *Maʿrifat buʿd al-shams min markaz al-arḍ li-Ḥabash* (p. 56): corresponds to MS Istanbul, ff. 151v:22–152r:5.

23 On the lettering of diagrams in Greek mathematics see the fascinating study by Reviel Netz (1999), pp. 12–67.

24 See Cajori (1928–29), I, p. 421.

3. *Bāb fī maʿrifat buʿd al-qamar min [markaz al-arḍ li-Ḥabash]*[25] (p. 57): corresponds to MS Istanbul f. 152r:6–15.[26]

4. Finally, the table on pp. 55–56 corresponds to that in MS Istanbul, f. 153r.[27]

1.2 General presentation of the treatise

The text we now publish belongs to the later period of Ḥabash's presumably long career, and it was possibly during an interval of about a decade before or after it that he composed his treatise on the melon astrolabe, with which it shares several elements of form and contents. It is indeed fortunate that this very interesting work by Ḥabash has been the object of a recent publication by three of the foremost specialists in the history of Islamic astronomy.[28] In a recent publication, David King has made the interesting observation that Ḥabash's universal plate for timekeeping by the stars might be the 'sister-instrument' of the medieval European *navicula de Venetiis*, a universal instrument for determining the time from the altitude of the sun, thereby formulating the conjecture that Ḥabash might also have been the inventor of the latter (not necessarily in the form of a ship).[29] Whereas it is not our intention to deny the possibility of an Islamic predecessor of the European *navicula*, nor to deny Ḥabash's ability to invent an ingenious in-

25 The upper-left corner of this page is damaged in the manuscript so that the end of the first few lines are illegible.

26 Items 1–3 have been translated and analysed in al-Saleh (1970).

27 For a description of those four items see Debarnot (1987), p. 49, under Vc–Vd, Ve, Vf and Table 29, respectively.

28 Kennedy, Kunitzsch & Lorch (1999).

29 King (1999), pp. 351–358, esp. the conclusion on p. 354: "The tentative connection of the idea behind the universal hour-dial on the *navicula* with Ḥabash is suggested by the fact that it was he who designed a device *for timekeeping by the stars* which is also highly ingenious" [emphasis in the original].

strument of this kind, we cannot at present confirm King's hypothesis.[30] Let us hope that further research will shed more light on this issue. We now turn to Ḥabash's own description of a very interesting device.

2 Text

Source: MS Oxford, Bodleian Marsh 663, pp. 205–206 and 239–247.

Editorial remarks: Words between acute brackets are our restorations to the text. Lacunae are rendered as $< \cdots >$. All *hamza*s have been silently restored, so that دائرة would be written دايرة in the manuscript, and جزء would be written as جزو , etc. Because we are dealing with a unique copy, we have thought appropriate to reproduce voweling and nunation (*tanwīn*) as they appear in the manuscript, but we have also indicated vowels whenever it facilitates the understanding of the text, especially with verbal forms. The copyist's usage of *shadda*s is rare but curious,[31] so our *shadda*s do not reflect those in the manuscript. We also represent the punctuation sign used by the copyist – a small circle open at the top, with a dot in the middle, similar to the letter ن – in this edition by the symbol ◇.

30 It should be noted, however, that at least three sets of trigonometric markings are featured on the universal instrument described in this paper as well as on the *navicula*: (1) the latitude scale along the upper half of the vertical diameter, which in both cases corresponds to the tangent of the latitude, (2) the lateral declination scale, and (3) the sine markings in the lower half (see further Section 5.2 below). It is also true that both instruments are clearly intended to solve similar problems of spherical astronomy; the *navicula*, however, strictly serves for finding the time from the solar altitude in a mechanical way, whereas the universal plate seems to be a much more versatile device, whose operation requires that the user be fully in control of his subject.

31 For example, we encounter in the *basmala* الرحّمن and in the first line الصفيحّة ! But in the first case the *shadda* might be intended for the preceding letter.

[رسالة في عمل الصفيحة الجامعة][32]

⟨205⟩

[١] إذا أردنا عمل الصفيحة[33] نعمل الصفيحة الجامعة أدرنا دائرة بقدر ما نريد كهيئة[34] دائرة ا ب جـ د ونقسم نصفها الأعلى ممّا يلي العلاقة بمائة وثمانين أقسامًا متساوية ونُخرج من مواضع الأجزاء التي نريد أن نقسم الصفيحة عليها في الربع الذي يؤخذ منه الارتفاع خطوطًا تقطع خطّ سمت الرأس المتّخذ[35] من العلاقة إلى أسفل الأرض على زوايا قائمة فتكون جيوبًا في الربع كهيئة[36] ما أخرجنا في ربع ا ب وهو ربع الجيوب

[١:٢] ونفرض في ربع ا د من الكواكب الثابتة ما نجد مجراه عن منطقة معدّل النهار مائلًا فيما بينه وبين خمسة وأربعين جزءًا[37] في ناحية الشمال أو الجنوب ونبيّن مواضع ما يعرض منها في ربع ا د فنأخذ من نقطة د في قوس جـ د بقدر أكثر ميل مجرى الكوكب الذي نريد أن نرسمه في الصفيحة كهيئة[38] ما أخذنا الميل الأعظم قوس د و خمسة وأربعين جزءًا ونخرج خطي و ز و ه

32 The words في الصفيحة الجامعة have been added in a later hand in the upper margin of p. 205. Cf. p. 109 above.

33 الصفيحّة MS

34 كهيه MS

35 المحدد MS

36 كهنة MS

37 جزوًا MS

38 كهيه MS

39 الكواكب MS

40 كهيّه MS

ونأخذ من نقطة دَ في قوس دَ وَ بقدر ميل الكوكب[39] الذي نريد كهيئة[40] ما أخذنا قوس دَ حَ ونخرج من نقطة حَ خطين موازيين لِـدَ هَ هَ جَ وهما خطّا حَ طَ يَ حَ ونخرج من نقطة يَ خطّ يَ كَ لَ موازيًا لخطّ هَ جَ ونأخذ برأس المدوار بقدر خطّ هَ طَ فنضع إحدى رجليه على مركز هَ والأخرى حيث بلغت من خطّ كَ لَ فنعلّم عليه علامة مَ ونخرج خطّ هَ مَ نَ يجوز على نقطة مَ ونقطع ربع اَ دَ على علامة نَ فعلى نقطة نَ نرسم مري[41] الكوكب الذي نجد مجراه مائلًا عن فلك معدّل النهار بقدر قوس دَ حَ في الشمال أو الجنوب

[٢:٢] فإن أردنا موضع مري الكوكب في ربع الصفيحة من باب الحساب ضربنا جيب ميل مجرى الكوكب عن فلك معدّل النهار في جيب ما ينقص الميل الأعظم من تسعين وقسمنا المجتمع من الضرب على جيب الميل الأعظم فما خرج من القسمة ضربناه في ستّين وقسمنا المجتمع من الضرب على جيب ما ينقص ميل الكوكب من تسعين فيخرج من القسمة جيب قوس موضع عرض مري الكوكب في الربع

[٣:٢] **مثال ذلك** وجدنا كوكب العيّوق في خمسة أجزاء وخمس دقائق من الجوزاء وعرضه في ناحية الشمال عن منطقة فلك البروج اثنين وعشرين جُزءًا وخمسين دقيقة ويتوسّط السماء مع تسعة وعشرين ⟨206⟩ جُزءًا وسبع وأربعين دقيقة من الثور ومجراه مائلًا عن فلك معدّل النهار في ناحية الشمال يكون ثلاثة وأربعين جزءًا وستّ وثلاثين دقيقة ونجعل قوس دَ حَ مثلا ثلاثة

41 مري is written above the line.

42 جزوًا MS

43 ميله MS

وأربعين جزءًا[42] وستّ وثلاثين دقيقة وجيبها خطّ ح ط ومثله[43] خطّ ي ك
< ... > مري الكوكب ميل مجراه عن فلك معدّل النهار ويعرض عند
مري الكوكب ميل مجراه عن فلك البروج[44] ◊

[شكل ١ [45]]

[١:٣] ⟨239⟩ ونعيد دائرة ا ب جـ د ونأخذ في قوس د جـ بقدر <بعد>
[46] مجرى أبعد كوكب يعرض في الصفيحة فتكون قوس جـ و[47] خمسة وأربعين
جُزءًا ونخرج من نقطة و خطّي و ز ح و يوازيان خطي د ه جـ ه ونأخذ من
نقطة د في ربع د جـ قوس د ط[48] بقدر عرض أي بلدٍ أردنا ونخرج خطّ
ه ط يقطع خطّ و ز على علامة ي ونخرج خطّ ك ي ل يوازي د ه ونأخذ
برأس البرجار بقدر[49] بعد ه ح فنضع أحد طرفيه على مركز ه والآخر حيث
ما وقع من خطّ ك ي ل فنعلّم عليه م ونخرج خطّ ه م ن[50] ونخرج ن س
موازيًا لخطّ د ه فيكون خطّ ه س جيب نصف فضل نهار كلّ كوكب يكون
مجراه مائلًا عن فلك معدّل النهار بقدر قوس جـ و[51] التي فرضنا خمسة وأربعين

44 فلك البروج should probably to be emended into فلك معدّل النهار

45 All figures and tables are reproduced in facsimile on pp. 126–129 below.

46 بقدر بعد] بقد MS

47 د و MS

48 جـ ط MS

49 بقدد MS

50 ر م ن MS

51 د و MS

52 نقدد MS

جُزءًا في الإقليم الذي يكون عرضه بقدر[52] قوس د ط فعلى موضع س نفرض خطّ تعديل نهار الكوكب في خطّ ه ح ◊

[شكل ٢]

[٢:٣] ⟨240⟩ وإن أردنا نصف فضل النهار الأطول لميل[53] خمسة وأربعين من باب الحساب ضربنا <جيب> ميل مجرى الكوكب عن فلك معدّل النهار في جيب عرض الإقليم وقسمنا المجتمع على جيب ما ينقص عرض الإقليم من تسعين فما خرج من القسمة ضربناه في ستّين وقسمنا المجتمع على جيب ما ينقص ميل الكوكب من تسعين فيخرج من القسمة جيب نصف فضل نهار الكوكب الشمالي أو جيب نصف نقصان نهار الكوكب الجنوبي عن النهار المعتدل في الإقليم

[٣:٣] **مثال ذلك** في إقليمنا حيث يكون العرض مثلًا قوس د ط أربعة وثلاثين جزءًا[54] وجيبها ع ط ثلاثة وثلاثين جُزءًا وثلاث وثلاثين دقيقة وستّ ثواني بالتقريب وقوس جـ ط ستّة وخمسين جُزءًا وجيبها ع ه تسعة وأربعين جُزءًا وأربع وأربعين دقيقة وثلاثين ثانية وثلاثين ثالثة وقوسا[55] د و جـ و كلّ واحدةٍ منهما[56] خمسة واربعين جُزءًا جيباهُما هما خطّا و ز ه ز كلّ واحد منهما وكذلك خطّ ه م اثنين وأربعين جُزءًا وخمس وعشرين دقيقة وخمس

53 لميل] لعرض MS

54 جزوًا MS

55 قوس MS

56 منها MS

57 ه د MS

58 قسمت MS

وثلاثين ثانية فإذا ضربنا خطّ ط ع في ه ز[57] وقسمنا[58] المجتمع من الضرب على خطّ ع ه يخرج من القسمة خطّ ي ز ومثله خطّ ه ك ثمانية وعشرين جُزءًا وسبع وثلاثين دقيقة فإذا ضربنا ه ك في ه ن وهو ستّون وقسمنا المجتمع على خطّ ه م يخرج من القسمة خطّ ه س أربعين جُزءًا وثمان[59] وعشرين دقيقة وعشر ثواني بالتقريب فتكون قوس د ن اثنين وأربعين جُزءًا وخمس وعشرين دقيقة بالتقريب

وكذلك نحسب جيوب تعديل نهار الكواكب لما بقي في سائر الأقاليم ولكن ليسهّل[60] علينا وجودها عند الحاجة نتّخذ جدولًا نبتديء به من الإقليم المخطوط على عرض اثنى عشر ونتّخذ تفاضل الجدول لجزئين[61] جزئين وننتهي إلى عرض أربعة وأربعين جُزءًا

[٤] ونضيف[62] إلى خطّ ه ج في ربع ب ج جدولًا يعرض فيه جيوب نصف فضل نهار الإقليم تكون ميسّرًا لتعديل نهار الكواكب الثابتة وعلى مثال ذلك أيضًا نضيف إلى خطّ د ه في ربع ا د[63] جدولًا يعرض فيه جيوب زيادات أنصاف النهار لرأس السرطان فيماسّ الإقليم المخطوط على عرض اثنى عشر وينتهى إلى عرض أربعة وخمسين لتعديل نهار أجزاء فلك البروج في الإقليم ◊

⟨241⟩

[جدول ١ :] جدول نصف فضل النهار لميل مه

59 MS ثمانية

60 MS يسهل] ليسهّل

61 Or possibly بجزئين

62 MS ونصف

63 ا ج

لتعديل[64] نهار الكواكب في الصفيحة
عرض المواضع – قسي نصف فضل النهار لميل مه
– جيوب قسي نصف فضل النهار لميل مه

[جدول ٢ :] جدول نصف فضل النهار لرأس السرطان
لتعديل نهار أجزاء فلك البروج في الصفيحة
عرض المواضع – قسي نصف فضل نهار السرطان
– جيوب قسي نصف فضل نهار السرطان

⟨242⟩
[جدول ٣ :] سمت قرص مري الكواكب في الصفيحة الجامعة
أسماء الكواكب
سمت قرص مري الكواكب في ربع الصفيحة الجامعة
ميل مجرى الكواكب عن معدّل النهار في الشمال
ما يعرض في الصفيحة الجامعة في المنطقة الجنوبية
ميل مجرى الكواكب عن فلك معدّل النهار

[جدول ٤ :] سمت قرص مُري الكواكب في منطقتي
فلك البروج وفلك معدّل النهار
أسماء الكواكب
سمت قرص مري الكواكب في منطقة فلك معدّل النهار
سمت قرص مري الكواكب في منطقة فلك البروج

[شكل ٣]

64 لتعديل] تعديل MS

[٥] ⟨243⟩ ونفرض في الوجه الآخر من الصفيحة منطقة فلك البروج ولتكن دائرة ا ب ج د[65] ونبتديء من نقطة آ لأوّل الحمل فنقسم ربع ا ب[66] بمطالع أجزاء فلك البروج في الفلك المستقيم على الأجزاء التي نقسم عليها الصفيحة إن أردناها نصفًا أو ثُلثًا أو سُدسًا فإن أردناها سُدسًا فيكون بمطالع ستّة أجزاء من أوّل الحمل قوس ا و خمسة[67] أجزاء ونصف ومطالع اثنى عشر جزءًا[68] منه قوس ا يب أحد عشر جُزءًا ودقيقةً ومطالع ثمانية عشر منه قوس ا يح ستّة عشر ⟨244⟩ جُزءًا وخمسة وثلاثين دقيقة ومطالع أربعة وعشرين منه قوس ا كد اثنين وعشرين جزءًا واثنتي عشرة دقيقة ومطالع آخر جزء من الحمل قوس ا ل سبعة وعشرين جُزءًا وثلاث وخمسين دقيقة ومطالع آخر جزء من الثور قوس ا س سبعة وخمسين جُزءًا وسبع وثلاثين دقيقة ومطالع آخر جزء من الجوزاء قوس ا ب[69] تسعين جزءًا[70] ونقسم الثلاثة الأرباع الباقية من الصفيحة كلّ رُبع بمثل أقسام نظيره

[٦] ونُقطِع قطر الدائرة العُظمى للدائرة الصغرى بقوسين مختلفين فتكون القوس التي[71] إلى ما يلي رأس الحمل بقدر قوس نهار الجدي في الإقليم والتي

65 MS ا كز ج د

66 MS ا كز

67 MS آ وخمسة

68 MS جر

69 MS ا كز

70 MS جزؤا

71 MS التي التي

72 MS راس راس

إلى ما يلي رأس[72] الميزان بقدر <قوس>. نهار السرطان في الإقليم <…> فنفرض الشظية عند موضع دائرة الصفيحة الصغيرة في الإقليم الذي نريد وكذلك نفرض في الشظية لجميع ما نريد من الأقاليم <…>

[٧] ونتّخذ عضادة الارتفاع مخرّقة في الوسط فيها مجرائين يجريان من القطب إلى حرف الدائرة يقطعان عرض العضادة باستواء على زوايا قائمة ونقسم وجه العضادة فيما يلي القطب على تجزيئة قطر الدائرة ثمانية[73] عشر[74] أقسامًا متساوية ونقسم الوجه الآخر بأقسام الجيوب كهيئة[75] ما قسمنا خطّ ا ه في ربع ا ب من الصفيحة

[٨] ونتّخذ أيضًا شظيّة دقيقة مختلفة الوجهين شبه ممتنعة فنظيرها[76] شبه الضبّة على قطر الصفيحة الآخذ[77] من موضع العلاقة إلى أسفل من الصفيحة الكبيرة ونتّخذ طول هذه الشظيّة أكبر من سدس قطر الدائرة للصفيحة العُظمى كي إذا ألزمنا مركزي الصفيحتين قُطبًا واحدًا وألزمنا ترابيعها خطًّا واحدًا باستواء نُلّقيها [؟][78] طرف الجدول من الصفيحة الصغرى <و ؟> طرف الشظية فإذًا نحن أجرينا الصفيحة الصغيرة جرت باستواء على قطر الصفيحة الكبيرة الآخذ من رأس الحمل إلى رأس الميزان ونجري الجدول المخرّق باستواء فيستغرق الشظية كهيئة[79] ما بيّنّا في هذه الصورة ونجري الصفيحة الصغيرة

73 MS ثمانة

74 MS وعشرين

75 MS كهيه

76 MS فنصيرها

77 MS الاخر

78 MS نلقيهم

79 MS كهيه

في بطن الكبيرة باستواء القطرين منهما حتى يكون البعد بين القطرين الآخذين منهما في وسط الدائرة الصغرى بقدر قوس نصف فضل نهار السرطان على نصف نهار المعتدل في الإقليم ◊

[شكل ٤]

العضادة الثانية

ظهر الصفيحة

[٩] ⟨245⟩ ونفرض في هذه الصفيحة داخل هذه المنطقة منطقة و ز ح ط[80] لفلك مُعدّل[81] النهار ونبتديء من خطّ ا ه فنقسمها بثلاثمائة وستّين جُزءًا مستويّة ونُفرِض مري الكواكب في المواضع التي تتوسّط السماء معها من فلك البروج في معدّل النهار ثم نهيّئ صفيحةً[82] صغيرةً يكون قُطرها بقدر ثُلثي قطر الصفيحة الكبيرة بالتقريب كهيئة[83] صفيحة ي ك ل م[84] ونقسمها بثلاثمائة وستّين جُزءًا متساوية و نخرق في موضع القطر منها حرفين مربّعين متوازيين متساوي الطول والعرض أحدهُما ⟨246⟩ من مركز الدائرة إلى ما يلي أوّل الأقسام والآخر من حرفها المقابل لأوّل الأقسام إلى ما يلي المركز شبه الجدولين ولا يصل أحدهما بالآخر فيكون فيما بينهما من الصفيحة بقدر

80 MS ز ح ط

81 MS مُعَدل

82 MS صفيحّةٍ

83 MS كهيه

84 MS ك ل م

85 MS تمسّكها

86 MS قد د

ما يمسكها[85] لئلّا ينفصل أحدهما من الآخر ونتّخذ شظيّة على قدر[86] الجدول الذي نخرقه في جوف الصفيحة إلى ما يلي المركز يكون شبه المجرى في الجدول غير فِلقة ولا المسطرة نركّبها في الوجه من الصفيحة التي تكون فيها الصفيحة الصغيرة إن شاء الله ◊

[شكل ٥]

⟨247⟩

[شكل ٦]
صورة العضادة

المجرى الأسفل مقسوم بستّين مقسوم على مقدار نصف قطر الصفيحة	المجرى الأعلى مقسوم على مقدار نصف قطر الصفيحة مقسوم بستّين

تمّ عمل الصفيحة الجامعة ولواهب العقل الحمد بلا نهاية والشكر بلا غاية

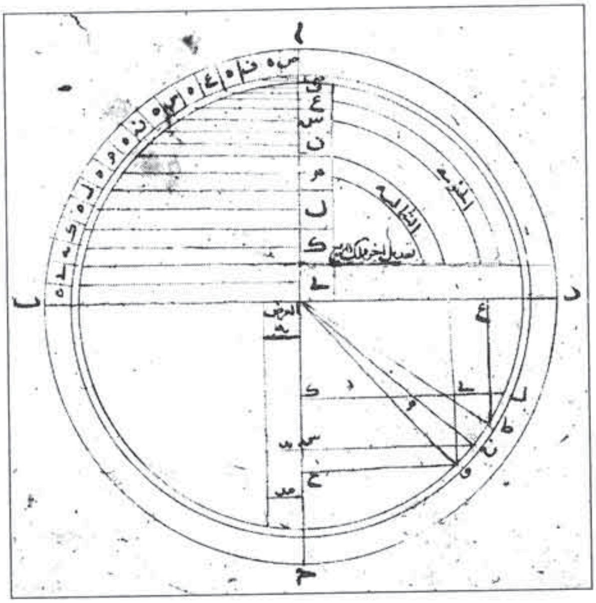

Figure 2

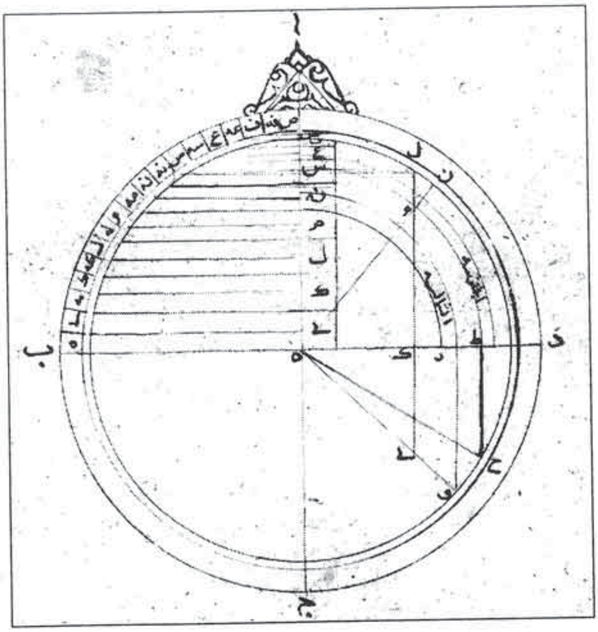

Figure 1

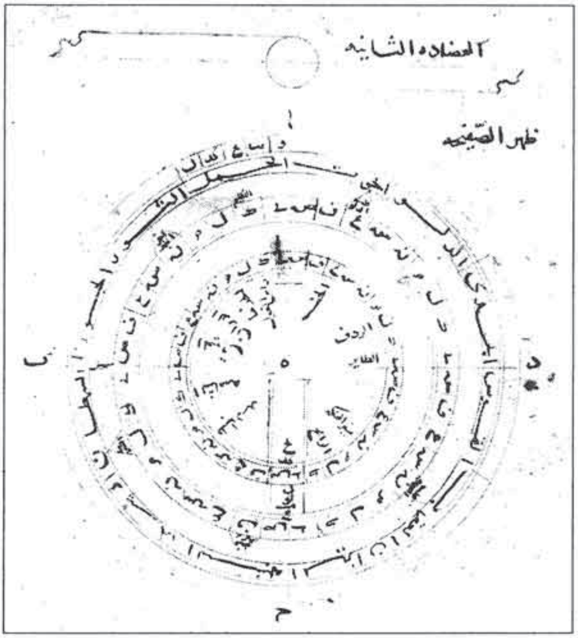

Figure 4

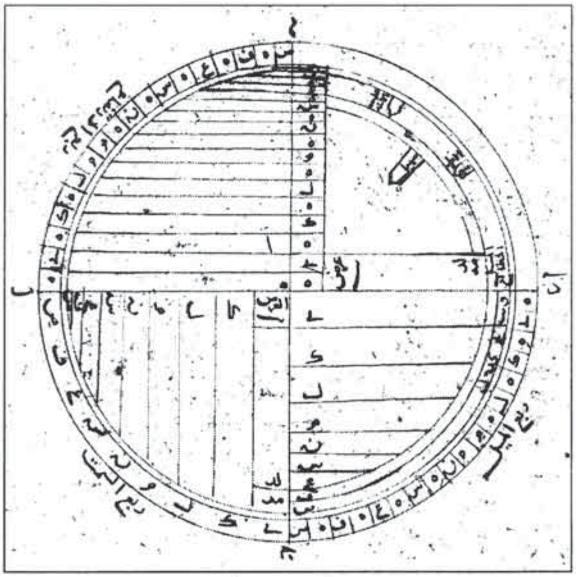

Figure 3

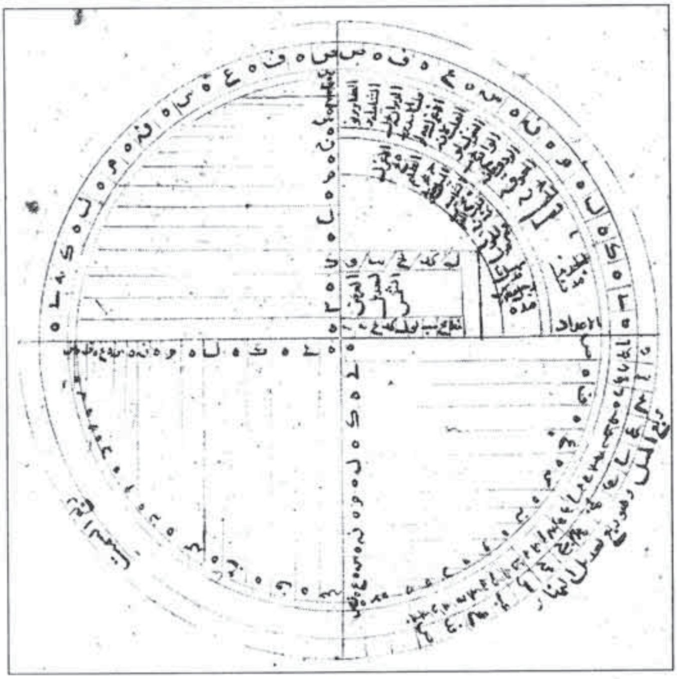

Figure 5

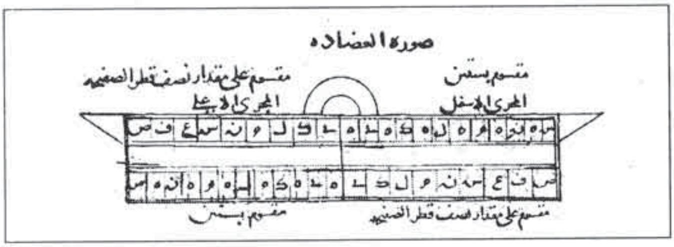

Figure 6

Table 2

Table 1

3 Translation

Notes of the editors: Words between parentheses are our additions to render the translation more intelligible to a modern reader. Text between square brackets correspond to emendations made to the Arabic text. All numbers are written with full words in the text; the only exception is the number 45 in the header of Table 1, which is noted in *abjad*. When the words *daraja* or *juz'* appear in the Arabic text, we render them in our translation with the word 'degree', but when they are implicitly assumed, we use the symbol '°' instead.

Treatise on the construction of the universal plate

⟨205⟩

In the name of God the Merciful and Compassionate
and to Him we call for help.

[1] If we want to construct the plate, we make the universal plate (as follows): we draw a circle in any size we wish in the form of circle *ABGD* and divide its upper half, adjacent to the suspensory apparatus, into 180 equal parts. From the degree markings with which we want to divide the plate in the quadrant for measuring the altitude, we draw lines cutting the zenith line, which goes from the suspensory apparatus to the lowest point (i.e. the centre *H*), at right angles (to it). These (lines) will be the sines on the quadrant as we have drawn (them) in quadrant *AB* and this will be the sine quadrant.

[2.1] We suppose in quadrant *AD* some fixed stars whose paths (across the sky) we find inclined by up to 45 degrees (declination) in the direction of north or south. We (would like to) mark the positions that result from these on quadrant *AD*. We measure from point *D* on arc *GD* the amount of the greatest declination of the star we wish to trace on the plate as we have measured the greatest declination on arc *DW* as 45 degrees. We draw two lines *WZ* and *WE* and measure from point *D* on arc *DW* the declination of the star we wish as we measure arc *DH*. We draw from point *H* two lines, (one) parallel to (line) *DE* (and the other to) *EG*. These will be the two lines *HT* and *YH*. We draw from point *Y* line *YKL* parallel to line *EG*. We measure with the compass (*ra's al-midwār*)[87] the length of line ET, and we put one of its two legs on centre E, the other where it reaches on line KL. There we mark point M. We draw the line EMN passing through point M and cutting quadrant AD at N. At this point N we trace the star pointer whose path (across the sky) we find inclined to the equator by the amount of arc DH to the north or to the south.

[**2.2**] If we wish (to determine) the position of the star pointer on the quadrant of the plate by the method of calculation, we multiply the sine of the declination of the star by the cosine of the greatest declination. We have divided the product by the sine of the greatest declination and the quotient we multiply by 60. Then we divide the product by the cosine of the declination of the star. The result will be the sine of the arc corresponding to the position of the star pointer on the quadrant.

[**2.3**] *Example.* We find the star Capella (*al-'ayyūq*) at 5 degrees and 5 minutes of Gemini. Its latitude in the direction of north of the ecliptic is 22 degrees and 50 minutes and it culminates (with the point of the ecliptic) at 29 ⟨206⟩ degrees and 47 minutes of Taurus. Its declination is 43 degrees and 36 minutes north. We make arc DH 43 degrees and 36 minutes. Its sine is line HT and line YK is the same. < …   … >[88] The star pointer (will indicate) the inclination of its path (across the sky) to the equator. The inclination of its path to the zodiacal belt[89] appears at the star pointer.

(Figure 1)

[**3.1**] ⟨239⟩ We draw again circle $ABGD$ and measure on arc DG the declination of the star with the greatest declination appearing on the plate, and

87 Here the author chose the unusual, but appropriate Arabic word *midwār* to designate a compass; elsewhere he uses the Arabicized Persian *birjār*.

88 There is a lacuna of several lines here. The missing part certainly continued with the geometrical construction and trigonometric calculation for finding the position of the pointer for Capella, according to the procedure presented in [2.1] and [2.2]. Moreover, the last two sentences appear to be corrupt, so our translation is problematic.

89 The expression 'zodiacal belt' should probably be emended into 'equator'.

arc GW[90] will be 45 degrees. We draw from point W two lines WZ and HW, (one) parallel to (line) DE (and the other to) GE and measure from point D on quadrant DG arc DT[91] as the amount of the latitude of any locality we wish. We draw line ET cutting line WZ at point Y and draw line KYL parallel to line DE. We measure with the compass the distance EH. We put one of its extremities on centre E, the other where it cuts line KYL and mark on it M. We draw line EMN [92] and draw NS parallel to line DE. Line ES will be the sine of the half-excess of daylight of any star whose declination equals arc GW[93] which we have taken as 45 degrees in that region whose latitude will be equal arc DT. At point S we suppose the line of the equation of daylight of the star on line EH.

(Figure 2)

[3.2] ⟨240⟩ If we wish the longest half-excess of daylight for declination[94] 45° by the method of calculation we multiply <the sine of> the declination of the star by the sine of the latitude of the region. Then we divide the product by the cosine of the latitude of the region. The quotient we multiply by 60. Then we divide the product by the cosine of the declination. The quotient will be the sine of half-excess of daylight of a northern star or the sine of the half diminution of daylight of a southern star with respect to daylight of the equinoxes in that region.

[3.3] *Example.* In our region where the latitude, is, for example, arc *DT* 34 degrees[95] and its Sine *OT* is 33;33,6 approximately. Arc *GT* is 56 degrees and its Sine *OE* is 49;44,30,30. Each of the arcs *DW* and *GW* are 45 degrees

90 The text has *DW*. This makes no difference in the particular case of $\Delta_{max} = 45°$, but in general the procedure would be wrong if *DW* were to represent the maximal declination.

91 The text has *GT*.

92 The text has *RMN* for *ZMN*.

93 The text has *DW*.

94 The text has 'latitude'.

95 Latitude 34° is for Samarra. See the discussion in the introduction on p. 110.

(and) each of their sines are the lines WZ and EZ. Likewise line EM will be 42;25,35. If we multiply (the length of) line TO by (the length of) EZ[96] and we divide the product by (the length of) line OE, the quotient will be (the length of) line YZ and (the length of) line EK is the same, namely 28;37. If we multiply (the length of) EK by (the length of) EN, namely 60, and then divide the product by (the length of) line EM, the quotient will be (the length of) line ES, namely 40;28,10 approximately and arc DN will be 42;25° approximately.

Likewise we calculate the sines of the equation of daylight of the stars for all remaining regions but in order to make it easier for us to find it, when it is needed, we make a table for which we begin with the climate inscribed as latitude 12 (degrees). We take the increment (of the arguments) of the table as two degrees, and we finish with latitude 44 degrees.

[4] We add to line EG in the quadrant BG a tabular scale (*jadwal*) on which appear the sines of the half-excess of daylight of the region to facilitate finding the equation of daylight of the fixed stars. In the same way we also add to line DE on quadrant AD [97] a tabular scale in which appear the sines of the half-excesses of daylight for the summer solstice (lit. the beginning of Cancer). The scale will touch the region marked for latitude 12° and go up to latitude 54°[98] for finding the equation of daylight of the degrees of the ecliptic in that region.

⟨241⟩

[Table 1 (right-hand side)]

Table for the half-excess of daylight for declination 45° for the equation of daylight of the stars on the plate. Latitude of the localities. Arcs of the half-excess of daylight for declination 45°. Sines of the arcs of the half-excess of daylight for declination 45°.

96 The text has *ED*.

97 The text has *AG*.

98 Perhaps we should read 44, as in Figure 3? But the last argument of Table 2 is 51! There is obviously some confusion here. It is possible that Ḥabash originally intended Table 2 to end with argument 54; in this case only the last line would be missing in the table.

[Table 2 (left-hand side)]

Table for the half-excess of daylight for the summer solstice for the equation of daylight of the degrees of the ecliptic on the plate. Latitude of localities. Arcs of the half-excess of daylight of the summer solstice. Sines of the arcs of the half-excess of daylight of the summer solstice.

⟨242⟩

[Table 3 (right-hand side)]

Direction of the disc of the star pointers on the universal plate. The names of the stars. Direction of the disc of the star pointers on the quadrant of the universal plate. Inclination of the path of the stars from the equator to the north. What appears on the universal plate on the southern belt. Inclination of the path of the stars from the equator.

[Table 4 (left-hand side)]

Direction of the disc of the star pointers on the belts of the zodiac and of the equator. The names of the stars. Direction of the disc of the star pointers on the equatorial belt. Direction of the disc of the star pointers on the zodiacal belt.

⟨243⟩

(Figure 3)

[5] We suppose on the other side of the plate the zodiacal belt and this will be circle *ABGD*.[99] We begin at point *A* corresponding to the beginning of Aries. We divide quadrant *AB*[100] with the right ascensions of the degrees

99 The text has *AKzGD*. '*Kz*' is written together as if it were the *abjad* notation for '27'. It is significant that the integer part of $\alpha(\lambda = 30°)$ is 27. On Figure 4 there is a hardly legible symbol vis-à-vis the end of Aries on the longitude scale. This could be the origin of the confusion. But it is strange that '27' (*Kz*) would represent this point instead of '30' (*L*), according to the convention introduced in the next few lines. And the systematic confusion in this section between the letters *Kz* and *B* to designate the end of the first quadrant is likewise difficult to understand.

100 The text has *AKz*.

of the ecliptic, according to the divisions with which we want to divide the plate, be it bi-, tri- or sexpartite. If we want it sexpartite, a right ascension of 6 degrees from the beginning of Aries will be arc *A*-6[101] (corresponding to) 5 degrees and a half; a right ascension of 12 degrees from it (i.e., the beginning of Aries) will be arc *A*-12 (corresponding to) 11 degrees and one minute; a right ascension of 18 degrees from it will be arc *A*-18 (corresponding to) 16 ⟨244⟩ degrees and 35 minutes; a right ascension of 24 (degrees) from it will be arc *A*-24 (corresponding to) 22 degrees and 12 minutes; a right ascension for the end of Aries will be arc *A*-30 (corresponding to) 27 degrees and 53 minutes; a right ascension for the end of Taurus will be arc *A*-60 (corresponding to) 57 degrees and 37[102] minutes; a right ascension for the end of Gemini will be arc *AB*[103] (corresponding to) 90 degrees. We divide the remaining three quadrants of the plate, each of the quadrants with the same divisions as on the one opposite it.

[6] We make the diameter of the largest circle divide the smallest circle[104] in two different arcs so that the arc in the direction of the beginning of Aries will correspond to the arc of daylight of Capricorn in that region and (the other arc) in the direction of the beginning of Libra will correspond to the < arc of > daylight of Cancer in that region. < ··· >[105] We put (lit. we suppose) the movable cursor (*shaẓiyya*) at the position of the circle of the small plate in the region we wish. Likewise we put (lit. we suppose) on the movable cursor for all of the regions we wish < ··· >

[7] Then we take an alidade (for measuring) the altitude, pierced at the

101 The notation *A-n*, which we have borrowed from Kennedy, Kunitzsch & Lorch (1999, p. 67), represents the arc going from *A* to a point labelled with the *abjad* notation for *n*, relating to the right ascension of an ecliptic arc of $n°$. Cf. p. 112

102 Read 47.

103 The text has *A Kz*.

104 This smaller plate has not been introduced yet, but see Section [9], which should logically precede this Section.

105 Lacuna?

centre, on which there are two slotted rules (*majrā*[106]) running from the pole (*quṭb*)[107] to the rim of the circle: these divide the breadth of the alidade equally at right angles. We divide the side of the alidade adjacent to the pole according to the graduation of the diameter in 18 [108] equal parts. We divide the other side according to the divisions of the sines in the form we have divided line *AE* on quadrant *AB* of the plate.

[8] We take also a fine cursor (*shaẓiyya*) with two different sides, one (side) like a catch (*mumtanaʿa*) and its opposite like the latch (*ḍabba*), on the diameter of the plate going down from the position of the suspensory apparatus to the lowest point of the large plate. We take the length of this cursor larger than one sixth of the diameter of the circle of the largest plate, so that if we make the two centres of the two plates (coincide at) one pole and if we make their perpendicular diameters (*tarābīʿahā*) (coincide) precisely (on) one line, then we will make them (i.e., their common diameters?) meet the (outer) side of the scale of the smaller plate <and> the (inner) side of the cursor.[109] Then we move the small plate which moves uniformly on the diameter of the larger plate, which goes down from the beginning of Aries to the beginning of Libra, and we move the pierced tabular scale (also) uniformly. The cursor will take up its position in the way which we have shown in this figure. We move the small plate at the inner part of the larger (plate) uniformly about (?) the two diameters of these two until the distance of these two diameters coming down from the two (common centres?) at the middle of the smaller circle will correspond to the arc of half-excess of daylight in Cancer over (the arc of) half-daylight at the equinoxes in that region.
⟨245⟩

(Figure 4)

[106] A *majrā* in this context means a slotted rule, in which the *shaẓiyya* can be moved.

[107] On an astrolabe *quṭb* refers to the broad-headed pin passing through the hole at the centre. See Kunitzsch (1982), p. 545.

[108] The text has 28.

[109] The Arabic text of the last sentence is quite obscure, and our translation is intended as a tentative reconstruction.

The second alidade
The back of the plate

[9] We suppose inside of this belt on this plate the scale $WZHT$[110] to represent the equator. We begin from line AE and divide (this scale) into 360 equal parts. We suppose the star pointers to be at those points which correspond to their mediation. Then we prepare a small plate whose diameter is approximately two thirds of the diameter of the large plate in the form of plate $YKLM$.[111] We divide it into 360 equal parts and we pierce along its diameter with two rectangular and parallel holes of equal length and breadth, one of them (running) ⟨246⟩ from the centre of the circle to the beginning of the divisions and the other from its rim opposite to the beginning of the divisions towards the centre like the two tabular scales. They should not join each other and there should be enough space in-between on the plate so that we can grasp it, and so that they do not separate from each other. We take a movable cursor (*shaẓiyya*) corresponding to the scale which we pierce inside the plate close to the centre, and it will be like the slotted rule (*majrā*) on the tabular scale without one half of the splits (*filqa*) and without the ruler. We mount it on the front of the plate bearing the small plate, if God wills.

(Figure 5)

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(Figure 6)
Figure of the alidade

The lower *majrā*	The upper *majrā*
divided into 60	divided as the radius of the plate
divided as the radius of the plate	divided into 60

The treatise on the construction of the universal plate is completed. To Him who gives understanding, praise without end and thanks without limit.

[110] The text has ZHT.

[111] The text has KLM.

4 The Tables

Two distinct sets of numerical tables are presented by Ḥabash in his treatise. In the first two tables, functions related to timekeeping are tabulated for a range of terrestrial latitude. The half excess of daylight and the Sine thereof are featured in Table 1 for a declination $\Delta = 45°$ and for arguments of latitude $\phi = 12°, 14°, \ldots, 44°$, and these can be expressed as

$$\text{arcSin}(\text{Tan}\,\phi) \qquad \text{and} \qquad \text{Tan}\,\phi$$

for the entries in the first and second columns, respectively, where the tangent function is to base $R = 60$ (i.e., $\text{Tan}\,\phi = R\tan\phi$). The same functions are also featured in Table 2, but for a declination corresponding to the obliquity of the ecliptic ε, so that they can be expressed as

$$\text{arcSin}\,\frac{\text{Tan}\,\phi\ \text{Tan}\,\varepsilon}{R} \qquad \text{and} \qquad \frac{\text{Tan}\,\phi\ \text{Tan}\,\varepsilon}{R}.$$

We present an edition of both tables as they appear in our sole source, together with recomputed values and restorations of the entries. It is indeed evident that Ḥabash's original tables – which were, as we shall see, very accurately computed – have heavily suffered at the hands of successive generations of copyists. The entries in the second columns of both tables under the heading 'recomp.' are based on exact recomputation with the modern formulae given above. Recomputations of the entries in the first column of each table are found by calculating the arcSine of the *restorations* of the corresponding entries in the second column.[112] Since this also corresponds to the logical order of compilation of the tables, we have displayed the second column before the first one. Errors in seconds are indicated next to those recomputations (following the convention error = text − recomputation); errors larger than 60 seconds that are due to scribal errors are indicated by '!!'. In the third column all entries obviously corrupted by scribal errors have

[112] For this purpose we have also compared the results with the exact arcSine against those found with Ḥabash's Sine table (see n. 119), using linear interpolation. But the few divergences from modern computation were not significant.

been restored, and the actual (original) errors have been given next to them; restored digits are underlined. Several entries in the first columns of Tables 1 and 2 have zeros in the seconds; this could indicate that either a copyist replaced illegible entries for the seconds by zeros, or that rounding and/or truncation occured at an early stage (either by Ḥabash or an early copyist). Closer examination, however, makes the first hypothesis inacceptable, for at least six entries in both tables have been clearly rounded *upwards*; indeed *all* entries with zero in the seconds can be explained by rounding to the nearest minute. Why some of the entries were rounded and others were not remains, however, a mystery. In the edition below rounding has been indicated by 'r'. The fact that Tables 1 and 2 reveal no numerical interdependance is rather surprising, since we would expect the entries in the second column of Table 2 with the same arguments ϕ as those in the second column of Table 1 to have been found by multiplying the latter by the constant $\mathrm{Tan}\,\varepsilon$, but this is not the case. Two independent (co)tangent tables appear to have been used.

The next set of tables contains lists of stars with various coordinates. Our analysis has revealed that these are identical with the star coordinates associated with the *Mumtaḥan* tradition,[113] and this new treatise by Ḥabash provides a further source for the recovery of the original coordinates. Table 3 gives the declination of 21 stars together with the quantity $\mathrm{arcSin}(\mathrm{Tan}\,\Delta)$, and Table 4 features 20 stars with their mediation and right ascensions. Since Figure 5 reveals star-pointers with the corresponding declinations, we have presented them in tabular form. We have also listed the names featured

113 The *Mumtaḥan* star table is preserved in its original form (ecliptic coordinates, declination and mediation of 24 stars for the year 214 H) on f. 192r of the Istanbul manuscript of Ḥabash's *Zīj* introduced above, and also in the eponym *Zīj* of Ibn Abi Manṣūr, of which a late recension is extant in MS Escorial árabe 927. In this manuscript we find two versions of the table in two different hands; the table on f. 95r is for the year 214 H and is virtually identical with that presented by Ḥabash. All extant star lists related to the original *Mumtaḥan* table have been edited and analysed as Part 1 of an unpublished study by Dorothea Girke (1988), which we have used together with the original manuscript sources. In our apparatus we use the following siglae: HZ = the version in the Istanbul manuscript of Ḥabash's *Zīj*; MZ = that on f. 95r of the Escorial manuscript. The sigla M refers to the *Mumtaḥan* table in general, whereas the number following it corresponds to a continuous numbering of the stars featured in it.

on the star-pointers illustrated in Figure 4. In Table 4 we have recomputed the right ascension α, which is not featured in the *Mumtaḥan* table, from the given values of the mediation μ, using the modern formula and assuming an obliquity of 23;35°.[114] The data on Figure 5 is badly degenerate, and we have marked the corrupt digits by underlining them. In the next column we give the declination from Table 3 and the *Mumtaḥan* table for comparision.

114 With $\varepsilon = 23;33°$ there are no changes except for entries 6, 10 and 13, where the errors become -1, 1, -1, respectively, instead of 0 everywhere.

Table 1

(b) second column: Tan ϕ

ϕ	MS	recomp.	err.	restor.	err.
12	12;46,15	12;45,12	!!	12;45,15	3
14	14;37,16	14;57,35	!!	14;57,36	1
16	17;12,18	17;12,17	1		
18	19;20,42	19;29,43	!!	19;29,42	-1
20	21;50,17	21;50,18	-1		
22	24;14,30	24;14,30	0		
24	26;13,00	26;42,49	!!	26;43,00	11[a]
26	29;17,50	29;15,50	!!	29;15,50	0
28	31;34,08	31;54,09	!!	31;54,08	-1
30	34;38,20	34;38,28	-8		
32	37;29,34	37;29,32	2		
34	40;28,15	40;28,14	1		
36	43;35,33	43;35,33	0		
38	46;53,00	46;52,38	22[a]		
40	50;20,44	50;20,46	-2		
42	54;01,27	54;01,27	0		
44	57;56,29	57;56,29	0		

(a) first column: arcSin(Tan ϕ)

ϕ	MS	recomp.	err.	restor.	err.
12	12;14,00	12;16,23	!!	12;16,00	r
14	14;26,00	14;26,17	r		
16	16;40,00	16;39,49	r		
18	18;18,00	18;57,38	!!	18;58,00	r
20	21;20,40	21;20,39	1		
22	28;49,00	23;49,49	!!	23;49,00	t
24	26;26,00	26;26,28	r		
26	29;14,00	29;11,30	!!	29;12,00	r
28	32;07,20	32;07,14	6		
30	35;15,45	35;15,43	2		
32	38;40,25	38;40,24	1		
34	42;25,00	42;24,59	1		
36	46;36,00	46;35,50	r		
38	51;28,18	51;23,17	!!	51;23,18	1
40	57;04,45	57;02,40	!!	57;02,45	5
42	64;14,40	64;12,40	!!	64;12,40	0
44	74;56,45	74;56,52	-7		

[a] These two entries *seem* to have been rounded to the nearest minute, and this would make them the only such cases in the second columns of Tables 1 and 2.

Table 2

(b) second column: $\mathrm{Tan}\,\phi\ \mathrm{Tan}\,\varepsilon/R$

ϕ	MS	recomp.	err.	restor.	err.
12	05;32,57	05;34,03	-66[a]		
15	07;01,06	07;01,06	0		
18	08;30,35	08;30,38	-3		
21	10;03,16	10;03,16	0		
24	11;39,42	11;39,42	0		
27	13;20,45	13;20,45	0		
30	15;07,09	15;07,20	-11	15;07,20	0
33	17;00,30	17;00,35	-5		
36	19;01,18	19;01,48	-30	19;01,48	0
39	21;52,36	21;12,37	!!	21;12,36	-1
42	28;34,55	23;35,02	!!	23;34,55[b]	-7
45	26;11,38	26;11,33	-5	26;11,33	0
48	29;05,24	29;05,23	1		
51	32;20,13	32;20,42	-29	32;20,43	1

(a) first column: $\mathrm{arcSin}(\mathrm{Tan}\,\phi\ \mathrm{Tan}\,\varepsilon/R)$

ϕ	MS	recomp.	err.	restor.	err.
12	05;18,14	5;18,24	-10	5;18,24	0
15	06;43,00	6;43,03	r		
18	08;09,15	8;09,13	2		
21	09;37,00	9;38,48	!!	9;39,00 ?	r ?
24	11;12,34	11;12,27	7	11;12,27? [d]	0 ?
27	12;51,10	12;51,07	3	12;51,7? [e]	0 ?
30	14;36,00	14;35,53	r		
33	16;28,00	16;28,03	r		
36	18;30,00	18;29,30	r		
39	20;42,00	20;42,06	r		
42	23;08,31[f]	23;08,36	-5		
45	28;53,00	25;53,06	!!	25;53,00	r
48	29;10,00	29;00,05	!!	29;00,00 ?	r ?
51	32;37,18	32;37,18	0		

[a] The fact that the original value used by Ḥabash was already affected by a significant error is confirmed by the corresponding entry in the first column: we have indeed $\mathrm{arcSin}\,5;32,57 = 5;18,24°$, and it is straightforward to assume that this was then miscopied as 5;18,14°. On the other hand, since $\mathrm{Sin}\,5;18,14° = 5;32,47$, it is also possible that the copyist error be only in the second column, but then we would have errors of -76 and -10 in the second and first columns, respectively, instead of -66 and 0. The original value of $\mathrm{Tan}\,12°\ \mathrm{Tan}\,\varepsilon$ in Ḥabash's table might have been 5;33,57 [error -6], which he could have later misread or miscopied as 5;32,57.

[b] Emending 23;34,55 to 23;34,50 would explain the entry 23;08,31 (= arcSin 23;34,50) in Table 2a. Another, less likely possibility is that '31' is a scribal error for '0' (whose *abjad* symbol could conceivably corrupt into '31').

[d] The corruption of '27' into '34' (كز → لد) is conceivable.

[e] The corruption of '7' into '10' (ز → ي) is conceivable.

[f] See note *a* to Table 2b.

Table 3

	M	Star name	Δ	arcSin(Tan Δ)	err.
1	—	*mankib al-jawzā'*	6;16 (*sic*)[a]	5;41[b]	[-1]
2	20	*al-nasr al-ṭā'ir*	4;57 (*sic*)[c]	6;18	0[d]
3	12	*al-shi'rā al-sha'āmiya*	0;00 (*sic*)[e]	7;20	-1[f]
4	6	*al-dabarān*	13;30	13;13	0
5	13	*qalb al-asad*	17;14	17;39[g]	![h]
6	23	*mankib al-faras*	21;45	23;31	0
7	15	*al-simāk al-rāmiḥ*	25;34	28;39	0
8	16	*al-munīr min al-fakka*	31;05	37;07	0
9	4	*ra's al-ghūl*	36;00	46;36	0
10	19	*al-nasr al-wāqi'*	38;12	51;54	0
11	22	*al-ridf*	41;02	60;30	0
12	10	*al-'ayyūq*	43;36	72;13	-1
13	5	*al-jadhmā*	44;54	85;08	-7
14	8	*al-surra* [i]	-2;37	2;37	0
15	14	[*al-simāk*] *al-a'zal*	-4;38	4;39	0
16	—	*al-ẓalīm*	-8;23	8;29	1
17	7	*rijl al-jawzā'*	-10;16	10;25	-1
18	11	*al-shi'rā al-yamāniya*	-15;48	1̲6;24[j]	-2
19	17	*qalb al-'aqrab*	-22̲;50[k]	24;54	0
20	21	*fam al-samaka*	-37;30[l]	50;07	0
21	24	*rijl qanṭūris*	-44;05	75;33	-2

[a] 6;16° is actually the value of Δ for the next star in this table (M20). [b] *Mankib al-jawzā'* might have been confused with *yad al-jawzā'* (M9), since 5;41 corresponds to $\Delta = 5;39°$; the declination of *yad al-jawzā'* given in the *Mumtaḥan* table is indeed 5;40°. If 5;41 is based on $\Delta = 5;39°$, then the error would be -1. [c] The *Mumtaḥan* table has 6;16° for M20 (see preceding entry). [d] Error for Δ = 6;16°. [e] The *Mumtaḥan* table has 7;17°. The preceding entry in this table has 4;57°, which could indeed be a scribal error for 7;17°. [f] Error for Δ = 7;17°. [g] This corresponds to a declination of 16;52° (there is no star with this value in the *Mumtaḥan* table). [h] Should be 18;4°. [i] *al-sūda* (!) MS. [j] 6;24° MS. [k] The declination of this star is not given in M, but recomputation from the given values of λ and β yields $\Delta = -22;50°$. The plate illustrated in Figure 5 (p. 246 of the manuscript) has indeed -22;50°!) MZ has rather -24̲;50°, where the 4 might be a scribal error for a 2. [l] M has erroneously $\Delta = -13;0°$ for this star. Recomputation of the declination from the *Mumtaḥan* values of λ and β yields -37;26°. The *Mumtaḥan* value must therefore be restored to -37;30°. The rounded value -38° is furthermore confirmed in Ḥabash's treatise on the melon astrolabe (Kennedy, Kunitzsch & Lorch (1999), pp. 88-89, no. 9)

Table 4

	M	star name	μ	α	α recomp.	err.
1	—	*al-ẓalīm*	$0^s15;58$	14;41	14;42	-1
2	4	*ra's al-ghūl*	$1^s00;09$	28;00	28;02	-2
3	5	*al-jadhmā*	$1^s02;59$	30;47	30;45	2
4	6	*al-dabarān*	$1^s24;15$	51;51	51;51	0
5	10	*al-ʿayyūq*	$1^s29;47$	57;34	57;34	0
6	7	*rijl al-jawzā'*	$1^s15;44$[a]	43;[1]4[b]	43;14	0
7	25	*suhayl*	$2^s2[7];40$[c]	87;24[d]	87;27	-3?
8	11	*[al-shiʿrā] al-yamāniya*	$2^s28;31$	88;20	88;23	-3
9	12	*[al-shiʿra] al-sha'āmiya*	$3^s08;00$	[9]8;46[e]	98;43	3
10	13	*qalb al-asad*	$4^s13;05$	135;35	135;35	0
11	24	*rijl qanṭūris*	$5^s20;30$[f]	1[71];1[8][g]	171;17	1
12	14	*al-simāk al-aʿzal*	$6^s05;53$	1[85];24[h]	185;24	0
13	15	*al-simāk al-rāmiḥ*	$6^s21;24$	199;45	199;45	0
14	16	*al-munīr min al-fakka*	$7^s13;04$	220;36	220;35	1
15	17	*qalb al-ʿaqrab*	$7^s21;44$	229;16	229;17	-1
16	19	*al-wāqiʿ*	$8^s29;27$	269;36[i]	269;24	12?
17	20	*al-ṭā'ir*	$9^s11;31$	282;38[j]	282;32	6?
18	22	*al-ridf*	$9^s28;00$	300;00[k]	300;07	-7?
19	21	*fam al-samaka*	$10^s24;47$[l]	326;33	327;06	-33?
20	2	*al-khaḍīb*	$11^s16;00$	347;[7][m]	347;08	-1

[a] M has $2^s5;44°$ (the corresponding α would be 63;49°). [b] 43;54° MS.
[c] $2^s24;40°$ MS. The corresponding entry of Ḥabash's *Mumtaḥan* table has been left empty (whilst *suhayl* is not featured in the *Mumtaḥan Zīj*). Ḥabash's treatise on the melon astrolabe gives $\lambda = 2^s29;10°$, $\beta = -75;10°$, and $\Delta = -51\frac{1}{3}°$; μ is given as $2^s29°$ in Table 3 of the same work but as $2^s27;40°$ in the text (148r:2,4), emended to $2^s29;40°$ by the editors. Since recomputation of μ from those ecliptic coordinates yields $2^s29;41°$, this emendation is indeed justified. Nevertheless, the value for the right ascension in the present table is obviously derived from the incorrect value $\mu = 2^s27;40°$ which is also confirmed twice in the treatise on the melon astrolabe. The corruption was thus already present in at least one copy of Ḥabash's star table when he compiled this treatise and the present work.
[d] Perhaps scribal error 87;27° → 87;24° (كز → كد) ? [e] 28;46 MS (!) [f] M has $\mu = 6^s19;32°$ (*sic*), which would correspond to $\alpha = 198;01°$. Recomputation from λ and β yields $\mu = 6^s3;46°$, which corresponds to $\alpha = 183;27°$. [g] 106;13° MS (قعا → قعو → قو ! and يج → يح). [h] 106;24° MS (قفه → قف → قو !). [i] Perhaps scribal error 269;26° → 269;36° (كو → لو) ? [j] Perhaps scribal error 282;33° → 282;38° (لج → لح) ? [k] Perhaps scribal error 300;5° → 300;0° ? [l] μ is omitted in HZ, and MZ gives the erroneous value $10^s18;24°$ (which is the λ of M22!); Ḥabash's treatise on the melon astrolabe (Kennedy, Kunitzsch & Lorch (1999), pp. 88-89, no. 9) has rather

$10^{s}27°$. Hence we have no possibility of controlling this entry against those sources. Perhaps $10^{s}24;47$ should be emended to $10^{s}24;\underline{1}7$, which would correspond to $\alpha = 326;37°$. Less likely is the possibility that $\alpha = 326;33°$ be a scribal error for 327;13° (شكو لج → شكز يكـ).
[m] 347;50° MS (ن → ز).

The Star Names with Declinations on Figure 5

Tab. 3	Star name	Δ	Δ (M)
	Outer segment (north)		
2	*al-ṭā'ir*	17;56	6;16
3	*al-sha'āmiya*	1;17	7;17
4	*al-dabarān*	13;30	13;30
5	*qalb al-asad*	17;14	17;14
7	[*al-simāk al-rāmiḥ*][a]	45;37	25;34
8	[*al-munīr min al-fakka*][b]	31;50	31;05
9	*al-ghūl*	36;–	36;00
10	*al-wāqi'*	18;42	38;12
11	*al-ridf*	41;50	41;02
12	*al-'ayyūq*	13;50! [c]	43;36
—	*al-khaḍīb*	??;?1	52;51[d]
13	*al-jadhmā*	44;51! [e]	44;54
	Inner segment (south)		
15	*al-a'zal*	5;38	4;38
16	*al-ẓalīm*	3;13	8;23
18[f]	[*al-shi'rā al-yamāniya*][g]	5(?);48	15;48[h]
19	*qalb al-'aqrab*	22;50	22;50[i]
20	*fam al-ḥūt*	87;30	37;30[j]
—	*suhayl*[k]	51;20[l]	51;20[m]
21	*rijl qanṭūris*	44;05	44;05

[a] [*al-simāk*] *al-a'zal* MS: the two *simāk*s have been confused!. [b] *al-qalb* (!) MS.
[c] The *nūn* for 50 minutes (ن) might be contaminated by the ق of *al-'ayyūq*. [d] The MS has something like وصا ! This star is not featured in Table 3, but 52;51 is the value from the *Mumtaḥan* table, which is also confirmed in the treatise on the melon astrolabe.
[e] The value in the text might be contaminated by the star-name or by the previous incorrect entry! [f] Between *al-ẓalīm* and this entry there is the caption *al-mayl al-janūbī*.
[g] The text has *sha'āmiya* (confusion with the other *shi'rā*!). [h] *al-shi'rā al-yamāniya* has $\Delta = -15;48°$ in Table 3. [i] This is the recomputed value (cf. note *l* in Table 3).
[j] This star is called *fam al-samaka* in Table 3. The treatise on the melon astrolabe has the rounded value -38° (Kennedy, Kunitzsch & Lorch (1999), pp. 88-89, no 9). [k] *Suhayl* is not featured in Table 3. [l] The minutes are written below the star name. [m] The

declination of *suhayl* is not given in HZ, but the value -51;20° is attested in Ḥabash's treatise on the melon astrolabe (Kennedy, Kunitzsch & Lorch (1999), pp. 88-89, no. 2).

The Star Pointers on Figure 4

Inner plate, CCW from top: *ra's al-ghūl, al-jadhmā, al-dabarān, al-ʿayyūq, al-shaʾāmiya, qalb al-asad, al-rāmiḥ, munīr al-fakka, al-ṭāʾir, al-ridf, al-khaḍīb.*
Outer plate: *al-ẓalīm, ākhir al-nahr* (= *Mumtaḥan* no. 1, but not in Tables 3 or 4), *suhayl, al-shiʿrā* [*al-yamāniya*], [*rijl*] *qanṭūris, qalb al-ʿaqrab, qalb al-dalw* (not in Tables 3 or 4 and not in the *Mumtaḥan* table).
Stars featured in Tables 3 and 4 that are missing on Figure 4: *al-surra, mankib al-jawzāʾ, rijl al-jazwāʾ, mankib al-faras, al-wāqiʿ, al-simāk al-aʿzal, fam al-ḥūt/al-samaka.*

5 Commentary

The aim of the following commentary is to present an analysis of the different sections of the text and to present together all information about the construction of Ḥabash's universal plate that can be obtained from it and from the accompanying tables and illustrations. Speculations about the way to use the instrument are beyond the scope of the present paper.

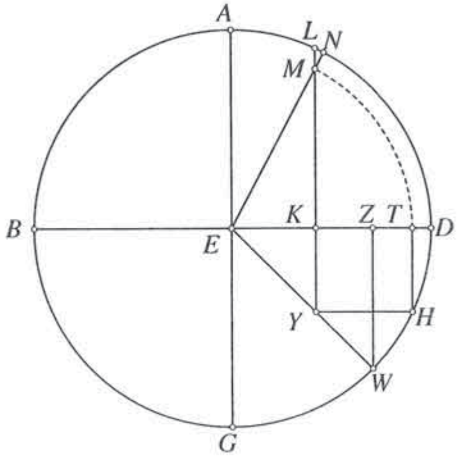
5.1 *The Text*

[1] The treatise begins somewhat abruptly by describing in a few sentences the construction of a sine quadrant in the upper-left quadrant *AB* of the plate *ABGD*.[115] The sine markings are traced horizontally, from each equal division of arc *AB* until line *AE*. *Cf.* our remarks on the illustrations of Figures 3 and 5 below.

115 On the sine quadrant see for example King (1995).

[2.1] The next step consists in representing the position of a given fixed stars of declination Δ on quadrant AD by a geometrical construction. The procedure is as follows:

Assume circle $ABGD$, centre E.
On quadrant DG find
$DW = \Delta_{\max} (= 45^\circ)$ and $DH = \Delta$.
Trace WE; $WZ \parallel GE$;
$HY \parallel DE$, with Y on EW;
$HT \parallel GE$, with T on ED.
Construct $YKL \parallel GEA$,
with K on ED and L on AD.
Find M on KL so that $EM = ET$;
extend EM to N on AD.
AN is the desired arc.



There results point N which gives the angular position of the star pointer.

[2.2] Next, a trigonometric formula is given as an alternative to the above procedure:

$$\operatorname{Sin} AN = R \frac{\operatorname{Sin} DH \ \operatorname{Cos} DW}{\operatorname{Cos} DH \ \operatorname{Sin} DW}.$$

Note that since arc DW is chosen by Ḥabash to be 45°, this quantity reduces to $\operatorname{Tan}\Delta$. We can easily prove the equivalence of this formula with the above procedure:

$$EZ = \operatorname{Cos}\Delta_{\max}, WZ = \operatorname{Sin}\Delta_{\max}$$

$$TH = KY = \operatorname{Sin}\Delta, ET = EM = \operatorname{Cos}\Delta$$

$$KY/EY = ZW/EW \quad \Rightarrow \quad EY = R\ \operatorname{Sin}\Delta / \operatorname{Sin}\Delta_{\max}$$

$$EK/EY = EZ/EW \quad \Rightarrow \quad EK = \frac{\operatorname{Cos}\Delta_{\max}}{R}\ R\ \frac{\operatorname{Sin}\Delta}{\operatorname{Sin}\Delta_{\max}}$$

$$\text{hence} \quad \operatorname{Sin} AN = R\ \frac{EK}{EM} = R\ \operatorname{Cos}\Delta_{\max} \frac{\operatorname{Sin}\Delta}{\operatorname{Sin}\Delta_{\max}}\ \frac{1}{\operatorname{Cos}\Delta}$$

from which we get the above formula given by Ḥabash.

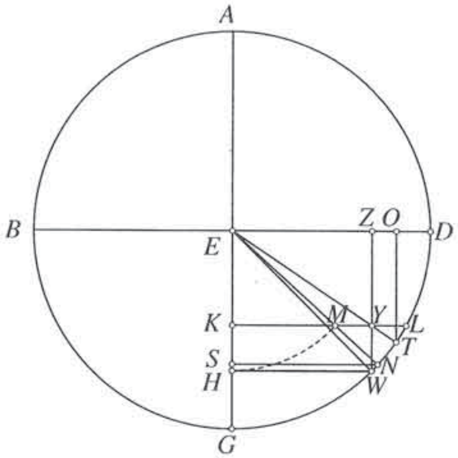
Remark: It should be noticed that the above procedure not only yields an angle AEN but also a radius $EM = R \operatorname{Cos}\Delta$. These in fact *could* represent the (polar) coordinates of the star-pointer in quadrant AD, although the text is not at all explicit about it. But this is suggested by the illustration on p. 243 of the manuscript.

[2.3] The worked example for the star Capella (*al-ʿayyūq*, α Aur) gives its ecliptic coordinates as $\lambda = 2^s5;5°$ and $\beta = 22;50°$ N, which agree with the entries of the *Mumtaḥan* star-table.[116] The mediation and declination are then given in the text as $\mu = 1^s29;47°$ and $\Delta = 43;36°$, values taken from Table 4, which themselves likewise agree with the entries in the *Mumtaḥan* table. Then various geometrical objects are associated with numerical values, but in the manuscript this Section breaks off after it has been mentioned that $DH = \Delta$ and $\operatorname{Sin}\Delta = HT = YK$. The last two sentences concerning the star-pointers are not clear.

[3.1] In this Section a geometrical construction of the half-excess of visibility $d(\phi,\Delta)$ of a star is presented with reference to Figure 2. The procedure can be summarized as follows:

[116] Cf. note 113 on p. 139.

On DG, find $GW = \Delta$
($= 45°$ in this example),
and $DT = \phi$.
Trace WE; $WH \parallel DE$, H on EG,
$WZ \parallel GE$, Z on ED
and $OT \parallel EG$, O on ED.
ET cuts WZ at Y;
construct $KYL \parallel ED$, L on DG.
Find M on KYL so that $EM = EH$;
extend EM to N on GD.
Construct $NS \parallel DE$, S on EG.
You obtain $ES = \mathrm{Sin}\, d(\phi, \Delta)$
and $DN = d(\phi, \Delta)$.



It is worth noticing that the above procedure is in fact a variant of the method described by Ḥabash in 'Problem 1' of his treatise on the melon astrolabe.[117] The only difference is that instead of finding M on KYL, one rather finds S on EG, so that $ES = E\Lambda$, where Λ is the intersection of EW and KL (Λ corresponds to L in the related diagram of the treatise on the melon astrolabe). It is not difficult to show the equivalence of both procedures. The first half of the construction – identical in both sources – can be explained by means of an 'analemma' construction.[118]

[3.2] The above is then expressed as a trigonometric formula as follows:

$$\mathrm{Sin}\, DN = \frac{\mathrm{Sin}\,\Delta\ \mathrm{Sin}\,\phi}{\mathrm{Cos}\,\phi}\ \frac{R}{\mathrm{Cos}\,\Delta}$$

which corresponds to the modern formula for the half-excess: $\sin d = \tan\phi\ \tan\Delta$.

[117] Kennedy, Kunitzsch & Lorch (1999), pp. 20–27 and pp. 94–97.

[118] For more details see *ibid.*, pp. 94–96.

We can demonstrate the equivalence of this formula with the construction in [3.1] as follows:

$$EH = \mathrm{Cos}\,\Delta, EZ = \mathrm{Sin}\,\Delta$$

$$OT = \mathrm{Sin}\,\phi, EO = \mathrm{Cos}\,\phi$$

$$EZ/ZY = EO/OT$$

$$EK = ZY \quad \text{and} \quad EM = EH$$

$$EK/EM = ES/EN$$

$$ZY = \frac{\mathrm{Sin}\,\Delta\ \mathrm{Sin}\,\phi}{\mathrm{Cos}\,\phi}$$

$$ES = R\,\frac{ZY}{EH} = R\,\frac{\mathrm{Sin}\,\Delta\ \mathrm{Sin}\,\phi}{\mathrm{Cos}\,\Delta\ \mathrm{Cos}\,\phi}$$

[3.3] The worked example chosen to illustrate this assumes $DT = 34°$, which is the latitude of Samarra (see p. 110 above), and its complement $GT = 56°$. We have

$$OT = \mathrm{Sin}\,34° = 33;33,6 \qquad \text{and} \qquad OE = \mathrm{Sin}\,56° = 49;44,30,30.$$

Both values are taken from Ḥabash's Sine table, itself directly derived from Ptolemy's Chord table.[119] We also have a declination of $GW = DW = 45°$, and $WZ = EZ = \mathrm{Sin}\,45°$. Furthermore we find $EM = EH = \mathrm{Sin}\,45° = 42;25,35$, and

$$EK = YZ = \frac{TO \cdot EZ}{OE} = \frac{\mathrm{Sin}\,34°\ \mathrm{Sin}\,45°}{\mathrm{Sin}\,56°} = 28;37,$$

so that

$$ES = \frac{R \cdot EK}{EM} = \frac{60 \cdot 28;37}{42;25,35} = 40;28,10,$$

and $DN = \mathrm{arcSin}(40;28,10) = 42;25°$.

119 Ḥabash's Sine table is preserved in MS Istanbul Yeni Cami 784/2, f. 127v. Entries are given to four places for each 0;15° of argument; the last digit is either 0 or 30, a consequence of the division of Ptolemy's Chords by 2. The use of Ḥabash's Sine table is suggested by the fact that his entry for Sin 56° noticeably differs from the exact value 49;44,32,7, and also from the result that other early Islamic Sine tables would yield.

[4] Two scales of the Sine of the half-excess of daylight are marked along the radii EG and ED of the plate. The first along EG is based on Table 1 and gives the half-excess for each 2° of terrestrial latitude from 12° to 44° and for the assumed maximal declination of a star 45°. The second one gives the same quantity for the sun at summer solstice, for each 3° of latitude from 12° to 51°. These quantities related to timekeeping by the sun are also needed for timekeeping by the stars, since at night one is basically interested to find the time elapsed since sunset, not the time since a particular fixed star has risen or culminated.

[5] A right ascension scale around the outer belt on the back of the plate allows to find the right ascension from the longitude, or vice-versa. Ḥabash gives the values of $\alpha(\lambda)$ for each 6° of λ up to 30°, and then for 60° and 90°, as follows: $\alpha(6) = 5;30$, $\alpha(12) = 11;1$, $\alpha(18) = 16;35$, $\alpha(24) = 22;12$, $\alpha(30) = 27;53$, $\alpha(60) = 57;[4]7$ [57;37 MS] and $\alpha(90) = 90$. These are the accurate values of the right ascension,[120] assuming the obliquity $\varepsilon = 23;35°$.[121] The scales on all other three quadrants are constructed symmetrically to that on quadrant AB.

[9][122] Inside of this zodiacal scale is a second ring divided into 360 parts representing the equator. Between it and the zodiacal scales there are star-pointers which point at the value of the mediation of various fixed stars. These elements can be easily recognized in Figure 4. A second plate of

120 The same values of the right ascension for the same series of arguments are also given in the treatise on the melon astrolabe, with the exception that there $\alpha(18)$ has been corrupted through scribal error into 1$\underline{7}$;35 (ستة → سبعة), but not emended in the published edition. Moreover, on p. 67, line 2 of the translation in Kennedy, Kunitzsch & Lorch (1999), one should read '$5\frac{1}{2}°$' instead of '5°' for $\alpha(6)$.

121 Cf. our discussion on p. 112 above.

122 Logically this Section should occur between [5] and [6], because the text begins by referring to "this belt" which can only be the zodiacal belt mentioned in [5]. Secondly, the information about the smaller plate which is introduced in this Section is necessary for the understanding of Section [6], where the smaller plate appears without having been properly introduced.

diameter *ca.* two thirds of the diameter of the larger plate is also mounted on the back. It has a similar scale along its rim which is also divided into 360 parts. Two rectangular portions of this smaller plate are pierced along the vertical diameter, leaving just the central region. These rectangular regions are clearly sketched in Figure 4, where we notice that the lower extremity of upper one has a triangular shape. Some movable cursor has also to be fitted within the slotted rule which goes along the vertical diameter of the larger plate, and which is provided with a tabular scale.

[6] The centre of the smaller plate can be freely moved within the slotted rule described in [9], which runs along the vertical diameter *AG*. The centre of this smaller plate has to be set so that its circumference will be divided by the horizontal diameter into two arcs, in such a fashion that the upper arc represents the daylight of the terrestrial latitude at winter solstice, and the lower arc, the daylight at summer solstice. There appears to be a latitude scale along the lower radius to allow for an easy setting of the small plate according to a given latitude. The last portion of this Section concerns a movable cursor, but the text appears to be seriously corrupt.

[7] This Section presents a description of the alidade that is illustrated in Figure 6, and which has to be mounted on the face of the plate. Both sides of the alidade bear two facing scales, one of them divided into 90 equal parts, the other one into 60 unequal parts defined according to the corresponding values of the Sines. The central part of the alidade is pierced out, presumably in order to see the scales that have been traced along two radii of the plate. At the side of this pierced rectangle is a slot in which a cursor can be moved between the centre and the extremity of the alidade, for marking distances from the centre. From Figure 6 we can deduce that the graduations on the alidade begin at the centre.

[8] Here the text describes some kind of locking cursor with catch and latch which has to be fixed to the vertical slotted rule on the back. Its length must be such that when the smaller plate is concentric with the larger one and their respective diameters are superposed, the locking device will touch

the outer side of the smaller plate. The text suggests a possible length of *ca.* one sixth of the diameter of the larger plate. A likely interpretation is that this cursor serves to lock the respective position of the two plates once they have been set for a particular latitude. The sentences that follow seem to describe the manner of inserting the smaller plate and a tabular scale into the slotted rule along the vertical diameter, so that the locking cursor will take up its place on the back. The last sentences seem to repeat in a different fashion the information that has been already given in [6], on the way to set the small plate relative to the other one so that the distance between their centres will represent a quantity corresponding to the half-excess of daylight at summer solstice. Given the less obscure instructions in [6], we find that this distance between the centres has to be $r \sin d(\phi, \varepsilon)$, where r is the radius of the smaller plate.

5.2 *The illustrations*

Given the defective state of the text, it is fortunate that our manuscript presents excellent illustrations. The copyist Ibrāhīm al-ʿUmarī drew the figures with care, using black and red ink. In view of the contradictory information displayed on Figures 3 and 5, it seems that the illustrations in his manuscript source were at least as defective as the text. We can be grateful that he did his best to carefully reproduce them. We now present a detailed description of Figures 3 and 5.

1. The altitude quadrant (labelled in Figure 3 *rubʿ al-irtifāʿ*) displayed in the upper left agrees very well with the instructions in Section [1]. On Figure 3 the labelling of the lines corresponding each 5° of altitude along radius EA has been traced in a rectangle overlapping the upper right quadrant.[123] This is probably a mistake, not repeated in Figure 5 where these labels are written on the left-hand side of line AE.

2. The quadrant of the azimuth in the lower left (labelled *rubʿ al-samt* on both illustrations) is another sine quadrant with vertical instead of

[123] Note that the lettering A, B, G, D, E in Figure 3 is consistent with that in Figure 1. Figure 5 is not lettered but we shall refer to it by using those same five letters.

horizontal lines. On Figure 3 the outer scale is labelled at each 10° from *G* to *B*, and the same labels are repeated along the radius *EB*. On Figure 5, however, the outer scale *BG* is graduated clockwise from 0 to 90 at each 5°, whereas the labels along the horizontal radius run from *E* to *B* as in Figure 3.

3. A 'quadrant of declination' (labelled *rubʿ al-mayl* in Figure 3) is displayed in both figures in the lower right, together with a scale along the rim. On Figure 5 it is labelled *rubʿ al-mayl wa-huwa rubʿ taʿdīl al-nahār*, 'quadrant of the declination, which is the quadrant of the equation of [half?] daylight'). It features a sine quadrant similar to that on the altitude quadrant; it is graduated along arc *GD* for each 5°, but the labels along the vertical radius *EG* run in the opposite direction, as on the quadrant of the azimuth described above. On Figure 3 they are only labelled along the vertical radius for each 10°.

   The scale along the rim serves to find the declination from the solar longitude. Its representation in Figure 3 is quite confusing: the outer scale is numbered from *D* to *G* at each 5°, and the inner band is only numbered in the first 30°-portion, starting at *D*, at each 6°. It is curiously labelled *al-mayl / al-maṭāliʿ* ('the declination / the ascension'), but does this perhaps rather belong to the upper right quadrant? On Figure 5 the outer ring is numbered for each 6° of longitude, also from *D* to *G*; and the inner ring is numbered with the corresponding value of the declination in degrees and minutes. The maximal value of δ, corresponding to the obliquity, ε, surprisingly turns out to be 23;33°, which is inconsistent with the values for the right ascension given in the text, which are based on $\varepsilon = 23;35°$![124] The values of the declination are reproduced in the table below. Errors against recomputed values are indicated between square brackets; these can be explained either by scribal mistakes in the manuscript tradition of our treatise, or by scribal mistakes in the seconds in the original declination table used by Ḥabash, which would have affected his rounding to the

[124] See our remark on p. 112, note 4 above.

nearest minute.

λ	$\delta(\lambda)$		λ	$\delta(\lambda)$	λ	$\delta(\lambda)$	
6	2;24		36	13;35	66	21;20	-4
12	4;46		42	15;30	72	22;19	-1
18	7;5	-1	48	17;16	78	23;0	
24	9;21		54	18;[5]2*	84	23;25	
30	11;31		60	20;15	90	23;33	

* 18;12 MS

4. The scale of Tan ϕ which is sketched in Figures 2 and 3 along radius EG is lacking in Figure 5. The scale of Tan ϕ Tan ε/R, however, is correctly represented in Figure 5 just above line ED, but its numbering is defective (it has the irregular series 12, 15, 18, 24, 30, 36, 42, 48, 59!). On Figure 3 it is not drawn to scale: the mark for latitude 44° should have a distance of *ca.* 25 parts of the sexagesimal radius from the centre, whilst it is drawn near the outer rim on this Figure.

5. The scales reminiscent of the 'shadow square' (on the back of astrolabes) displayed in Figure 5, whose lower base coincides with the scale above, are quite mysterious. They are labelled *al-ʿarḍ li-taʿdīl al-shams* ('the latitude for the equation of the sun'), but the last two words should probably be read *taʿdīl al-samt*, 'the equation of the azimuth', an auxiliary quantity used by Muslim astronomers in azimuth calculations.[125] The construction and purpose of the scale represented on the upper edge of the 'square' is not clear at all. It should be noticed that the height of the rectangle on the illustration measures Sin $20° \approx 20.5$, but this is probably not conform to the original design of the instrument.

6. Three star-pointers are represented in Figure 3 in the upper right quadrant for the stars *qalb al-asad*, *suhayl* and *munīr al-aʿzal*. Their respective angular distance from point A, measured on the illustration,

125 See King, *SATMI*, I-1.2 and I-8.

are approximately 25°, 42° and 55°. These do not correspond with what can be obtained from the formula arcSin(TanΔ) given in [2]. The presence of *suhayl* on this figure as well as in Figure 5 contradicts Ḥabash's information in [2] that the maximal declination of the stars represented is 45°, for the declination of *suhayl* is 51;20° south (see Table on p. 145 above, where we also encounter *al-khaḍīb* with [reconstructed] declination 52;51°). The position of the star names with their accompanying declinations on the same quadrant in Figure 5 is unrelated to the position of their respective pointers. The information is displayed there in a tabular fashion, and we have reproduced it on p. 145.

Figure 4 corresponds rather well with the textual information of the back in Sections [5], [9] and [6], and has been treated above in our commentary on the text. We have listed the star-pointers featured on this illustration on p. 146. On the smaller plate only the names of the stars are written, and their pointers have not been drawn. Also featured on this figure is the second alidade, which has to be mounted on the back of the instrument; on the illustration it does not bear any graduation.

5.3 The tables and their purpose

We now turn to the tables which we have edited and analysed in Section 4 above. Tables 1 and 2 clearly serve to construct the scales described in Sections [2] and [3] of the text. The second column of Table 3 readily gives the angular position of the star-pointers in the upper right quadrant of the front. Apparently, the declination of each star has to be written near its pointer (as suggested by Figure 5), which would explain why this information is given in the first column of Table 4, as well as in Figure 5. The star coordinates (mediation and right ascension) in both columns of Table 4, on the other hand, serve for constructing the star-pointers on the larger and smaller plates on the back, respectively, according to the instructions in Sections [5] and [9] of the text.

6 Conclusion

Ḥabash's universal plate is a complex instrument which features on the front three sine quadrants, special star-pointers in a fourth quadrant, and some trigonometric scales. The quantities provided by these various markings can be transferred by means of the alidade with cursor and scales. The discs on the back of the instrument provide the user with relevant coordinates of some fixed stars in relation to the ecliptic and the local horizon. The exact procedure intended by Ḥabash for using this instrument, however, still needs to be reconstructed.

The purpose of our endeavour was to make Ḥabash's description of this unusual device, extant in a unique manuscript, available for the first time, together with a commentary on the text and the accompanying tables and illustrations. We repeat the hope expressed in the introduction that colleagues will be able to help us in the further elucidation of the use of this fascinating instrument from mid-9th-century Abbasid culture.

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