Two Early Persian Texts on Shadow Schemes and the Regulation of the Prayer Times [1]

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Abstract: In this article, we shall elucidate the use of shadow lengths for regulating prayer times among Zoroastrians, focusing on a part of a Zoroastrian religious book entitled *Shāyest Nāshāyest*, written in Middle Persian (Pahlavī) language probably around the 9th c. A.D. Then, we will compare this text with a part of another Persian work entitled *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm* which is written in the second half of the 6th century after Hijra (the 12th c. A.D.) by Abū Muḥammad al-Najjār in Islamic civilization. For this purpose, we will recalculate the given values for the shadow lengths of the gnomon – taken as the height of a man – in both texts and find the best fitted latitudes for them. Finally, we will mention the similarities of the two texts to investigate the possibility of a historical relationship between them. Moreover, the transmission of this timekeeping method among some civilizations will be discussed.

Keywords: shadow schemes, prayer times, timekeeping, *Shāyest Nāshāyest*, *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm*, Zoroastrians, gnomonics

[1] This paper develops a part of my M.A. thesis entitled: "Theoretical Foundations of the Sundials in Islamic Civilization, with Translation and Commentary of Ibn al-Haytham's *Risāla fī al-Rukhāmāt al-Ufuqīya* (Treatise on Horizontal Sundials)" under the supervision of Prof. M. Bagheri.

1. Introduction

Several kinds of sundials were commonly used in various civilizations as astronomical instruments for telling the time of day. We have quite considerable materials to elucidate the designs of sundials and the methods for their construction in such civilizations as Egypt, Greece, Rome, China, India and Islamic civilization. However, our information is too limited to analyze the use of sundials by Zoroastrians in Iranian pre-Islamic astronomy due to the lack of original sources.

We can find some evidence of the use of a gnomon shadow length for determining the time which has elapsed since sunrise or noon, or remains until noon or sunset in some ancient texts. In addition to the Babylonian origin for arithmetical foundations of the shadow schemes, it seems that there was a purely Greek origin, by which we can trace the measurement of time based on the length of one's shadow in terms of his feet back to the fourth or fifth century B.C. in Greek astronomy.[2]

In another example two Indian sources named *Arthaśāstra* (shortly before 300 B.C.) and *Śārdūlakarṇāvadāna* (anti-caste tract) include the values of noon-shadow length of a gnomon for various dates probably inspired by Mesopotamian sources.[3]

In about 450 A.D. Palladius Ritilius Taurus Emilianus indicated shadow lengths based on one's height for each hour of the day during each month of the year in Sicily. [4] This timekeeping method was used in the Mediterranean and spread in some other regions. Tiberius'[5] timekeeping table (around 850 A.D.) for the probable latitude 53° and Bede's table (between 700-730 A.D., England) are other examples of this timekeeping method.[6]

New evidence which has recently been found shows that Zoroastrians used this method for regulating their prayer times as did Muslims.[7] In the pre-Islamic Sassanid dynasty (226-652 A.D.), Zoroastrians were a majority in Iran and used

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[2] Neugebauer, pp. 736-740

[3] Pingree, pp. 1-12, especially pp. 3-6

[4] Harris, http://archive.org/stream/jstor-287167/287167_djvu.txt

[5] Tiberius was a monk who resided in a monastery situated in a valley of the Anglo-Saxon countryside at very nearly 53° latitude and prepared the timekeeping table there around 850 A.D. Kellogg and Sullivan, pp. 8-9

[6] Kellogg and Sullivan, pp. 1-13

[7] On Muslims' method for determining their prayer times based on the shadow lengths see King, 1990, pp. 192-204; On the origin of the definitions see King, 2004-05, "On The Times of Muslim Prayer".

the Sassanid calendar.[8] We have two sources that show us the existence of Zoroastrians' knowledge about gnomonics at that time. The first one is *Ifrād al-Maqāl fī Amr al-Ẓilāl* of al-Bīrūnī, according to which there was a part in the *Sh̲āh Zīj* (Royal Astronomical Handbook) compiled in the Sassanid dynasty. Unfortunately, no copy of it has survived. The fragment quoted by al-Bīrūnī is about determining the solar hour angle based on the shadow length of a gnomon by using trigonometric methods.[9]

Further evidence of probable astronomical knowledge of the Zoroastrians applied in gnomonics appears in the 21st chapter of the *Sh̲āyest Nāsh̲āyest*, a religious book of the Zoroastrians, where the text explains the way by which one can use the shadow of a gnomon for regulating his prayer times.[10] It seems that the main parts of this book were originally compiled in the late Sassanid era[11] (the 6th and 7th c. A.D.) by an anonymous author and probably other parts were added in Islamic period around the 9th c. A.D. However the earliest remaining manuscripts of this work were copied later, sometime between 1351 and 1397 A.D.[12] and it is not certain that the 21st chapter of this book is a part of the original text. Furthermore, it is noteworthy that a large number of remaining Zoroastrian religious texts including materials on praying, liturgy and worship ceremonies were written in Middle Persian (Pahlavī) language even after the 9th c. A.D.[13] Before the time of Zoroaster (whose religion flourished almost continually from the 6th c. B.C. to the 7th c. A.D.[14]), pagan Iranians prayed three times a day, at sunrise, noon and sunset. These times divided the daylight hours into two periods. *Hāwanī* was the morning one, *uzerīn* (or *uzayra*) was the afternoon one and the *aiwīsrot̲h̲rem* was the evening one. Now Zoroaster

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[8] This calendar included 365 days in twelve months and five extra days at the end of the twelfth month and one extra month per 120 years. Al-Bīrūnī, 1923, pp. 43-45; Taqizadeh, p. 52-69

[9] Here is al-Bīrūnī's account of the *Sh̲āh Zīj* method for finding the solar hour angle: "In the *Sh̲āh Zīj*, for ascertaining the (part of the day) passed he directs division by the sine of the altitude at the time, of a thousand and eight hundred. There comes out the hypotenuse of the shadow for that time, and by it he divides the product of the length of the computed sine (i. e., the day sine) and the hypotenuse of the noon shadow. What comes out is subtracted from the length of the computed day sine, and the remainder he subtracts from a hundred and fifty, and the arc sine of the remainder is found. And so it will be the equation of the sine. If the altitude is easterly, subtract the equation of the sine from ninety, and if the altitude is westerly increase by it (the) ninety, and there results the arc of revolution of the sky". Kennedy, 1976, vol. 1, p. 199.

[10] Prof. M. Bagheri was first informed by the late Mr. H. San'ati Zadeh of the presence of this passage orally and he conveyed the idea to me.

[11] *Sh̲āyest Nāsh̲āyest*, p. 13 (intro)

[12] Ibid, p. 19-20 (intro)

[13] Boyce, p. 153

[14] Ibid, p. 1

introduced two other times for praying. One of these new times, named *rapīthwan*, began at noon and extended into the end of the first part of the afternoon. The second time, whose name was *ushah* (or *ushahīn*), began at the midnight and extended until daybreak of the next day.[15] So, the five prayer times of the Zoroastrians were: *hāwanī*, *rapīthwan*, *uzerīn*, *aiwīsrothrem* and *ushahīn*.

In the first part of our text, the values of the length of one's shadow in terms of one's feet are given for noon when the sun is at the beginning and the middle of each zodiacal sign during a year.[16] In the second part, the values of shadow length are given for determining the *uzerīn* prayer time at solstices and the beginning of Leo. In addition, the author presented a simple arithmetic rule for calculating the *uzerīn* prayer time for each month. Probably he cited the *uzerīn* prayer time at solstices as a clue to use this rule, and since this rule would not be valid for the beginning of Leo,[17] he cited the *uzerīn* prayer time for this longitude separately.[18]

Shadow Schemes in the Islamic Period

In Islam, there were two distinct traditions in astronomy and astronomical timekeeping. The first was based on mathematics, especially trigonometry, and involved extensive tables for timekeeping by the sun and stars. This does not concern us here, the second was folk astronomy, based on numerical, schemes. It is to this tradition that our material directs us. Widespread use of a gnomon shadow schemes in Islamic folk astronomy has been shown by giving some examples of different Islamic sources which include one or more parts about the use of gnomon shadow length for different purposes such as geographical or religious aims.[19] As we know, Muslim geographers divided the northern hemisphere of the earth into seven climates (*iqlīm*), following (perhaps) Ptolemy.[20] They distinguished the climates based on one's own shadow length in

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[15] Ibid, p. 32

[16] *Shāyest Nāshāyest*, pp. 251-253

[17] As we know, the variation of the solar declination is not linear over the course of the year and it decreases very slowly from 90˚ to 120˚ of ecliptic longitude (from the beginning of Cancer to the beginning of Leo); see the third paragraph of the part "The Values of Shadow Length for the *Uzerīn* Prayer Time" of the present paper.

[18] In a manuscript of the *Shāyest Nāshāyest* which is preserved in Navsari (India), this chapter is written under the title "The Truth of the *Rapīthwan* Prayer Time and the *Uzerīn* Prayer Time", Meherjirana, f. 26 v

[19] King, 1990, pp. 191-249

[20] Ptolemy refers to seven climata in his *Almagest*, Book VI, Part 11, p. 315

terms of one's feet at midday on the equinoxes.[21] We can trace this way for determining latitude back to Hipparchus.[22]

We can also find similar texts in the Islamic sources in which shadow lengths of a gnomon for performing two prayers of the Muslims were determined.[23] One of them, is a kind of encyclopedia of sciences entitled *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm* which was written in Persian by Abū Muḥammad al-Najjār probably in the second half of the 6th century after the Hijra (the 12th c.A.D.), in Qazwīn.[24] In the 27th chapter of this book ("On the Science of Astronomy") the author has indicated three values of midday shadow lengths in feet for each zodiacal sign when the sun is in the first, second or third ten days of each zodiacal sign.[25] In the following, we will survey the values of the shadow length which are indicated in this book. We can also find some other examples among Islamic sources in which one's shadow lengths is indicated for determining the time of day.[26] We now turn to the translations of sections of the two treatises that are the principal topic of this paper.

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[21] al-Muqaddasī, pp. 59-61; al-Ḥamawī, Vol. 1, pp. 33-36; al-ʿUrḍī, pp. 55-61; al-Bīrūnī, 1988, p. 190

[22] Berggren and Jones, p. 28

[23] King, 2004-05, vol. 1, pp. 476-477, 495, 507

[24] Ansari, p. 329-332; Mr. Daneshpazhooh stated that the author of this book is unknown [*Yawāqīt al-ʿUlūm wa Darārī al-Nujūm,* Edited by Daneshpazhooh, pp. 4, 6 (Intro)]

[25] *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm*, pp. 242-244; This work is published in Iran based on the three manuscripts: Tehran, Majlis, No. 5943; Tehran, Loghatnameh Dehkhoda Institute, No. 19; Aya Sofia Library, No. 4359

[26] Modarres Razavi, pp. 622-623; King, 2004-05, vol. 1, pp. 223-225; Noori, pp. 315-317

2a. Translation of the Fragment of the *Shāyest Nāshāyest* on Finding Prayer Times [27]

Chapter XXI, translation[28]

1. I write of the indication of the midday shadow; may it be auspicious.

2. (when) the sun (is) in Cancer, (the shadow is) the sole of a man's foot; at the fifteenth (degree) of Cancer, (it is) one foot; (When) the sun (is) in Leo, (it is) one foot and a half; at the fifteenth of Leo, (it is) two feet; (When) the sun (is) in Virgo, it (is) two feet and a half; at the fifteenth of Virgo, (it is) three feet and a half; at Libra, four feet and a half; at the fifteenth of Libra, five feet and a half; at Scorpio, six feet and a half; at the fifteenth of Scorpio, seven feet and a half; at Sagittarius, eight feet and a half; at the fifteenth of Sagittarius, nine feet and a half; at Capricorn, ten feet; at the fifteenth of Capricorn, nine feet and a half; at Aquarius, eight feet and a half; at the fifteenth of Aquarius, seven feet and a half; at Pisces, six feet and a half; at the fifteenth of Pisces, five feet and a half; at Aries, four feet and a half; at the fifteenth of Aries, three feet and a half; at Taurus, two feet and a half; at the fifteenth Taurus, two feet; at Gemini, one foot and a half; at the fifteenth of Gemini, one foot.

3. May the end of the (indication of) the midday shadow be good.

4. I write of the indication of the afternoon; by the help of the *Yazda*, may it be good and auspicious.

5. When the day is on the increase and the sun enters the beginning of Cancer and the shadow becomes six feet and two parts, one keeps the *uzerīn gāh*.

6. Every thirty days, (the shadow) increases always by one foot and one-third, now for every period of ten days, the reckoning is always half a foot; (When) the sun (is) at the beginning of Leo, the shadow (is) seven feet and a half.

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[27] This English translation has been published in the book *The Supplementary Texts to the Šāyest nē-Šāyest* by Kotwal (Kotwal, pp. 87-89). In this translation, Kotwal has used modern numerals for the values, unlike the original text. So, we have replaced the numerals by the words here.

[28] This chapter has been written under the title "The Truth of the *Rapīthwan* Prayer Time and the *Uzerīn* Prayer Time" in the Meherjirana Library manuscript (f. 26 v).

7. In conformity with this, in every zodiacal sign, similarly, and in all months, similarly, till the sun enters the beginning of Capricorn, (when) the shadow becomes fourteen feet and two parts.

8. In Capricorn, it decreases again by one-third of a foot; from there (where) it turns back (its course) just like the decrease of night and the increase of day, (so) each one of the months decreases always by one foot and one-third; so every ten days the reckoning is always half a foot till it comes again to six feet and two parts. Every zodiacal sign similarly, and the months similarly.

8a. I have written and finished it, I, the servant of the Faith, Mihr-Ābān son of *Kay-Husraw*, priestly-born.

8b. The writing is mine; I (am) the teacher, Ērbad *Pēšōtan*, son of *Rām*

2b. Translation of 27th Chapter of the *Yawāqīt al-ʻUlūm wa Darārī al-Nujūm*[29] on Finding Midday Shadow Length

The question twelve: How to know the solar transit (*zawāl*) based on the [length of one's shadow in terms of his own] feet?

Answer: [They] know the time of the solar transit based on the increase of the shadow length of gnomons. [And their method] is such that they pierce a straight stick to the earth [perpendicularly], so that its shadow stretches towards west at the sunrise. In this case, when the sun rises the shadow length shortens and reverts from west, and stops when the sun reaches its culmination. Then, the shadow length increases again. Whenever the beginning of increasing of the shadow length can be known, that time is the time of the solar transit. And in the divine wisdom, the sun has passed the meridian before this time, but in the legal elaborations, whenever [the decreasing of the solar altitude] can be detected is the time of midday. And the midday shadow length differs in various times and locations. The maximum value of the shadow length is eleven feet in Qazwīn[30] and Rayy[31]. But its example is that when the sun enters Aries, during the first ten days [the length of one's shadow] is four feet and a quarter[32], and during the second ten days it is four feet and one sixth [of a foot][33], and during the third ten days it is three feet and a half[34].

And when [the sun] enters Taurus, during the first ten days [the length of one's shadow] is on sixth of a foot less than three feet, and during the second ten days it is two feet and two parts of a foot, and during the third ten days it is two feet and one sixth [of a foot].[35]

And when [the sun] enters Gemini, during the first ten days [the length of one's shadow] is one foot and four sixths of a foot, and

[29] For this translation, we have used two versions of this work; one of them is published in 1985 by the late Mohammad-Taqi Daneshpazhooh, and the other is a manuscript which is preserved in the Loghatnameh Dehkhoda Institute (no. 95). In the cases of having different records of values for a certain shadow length, we have chosen the correct one and cited the other in the footnote. In the following, we will use "LD" for the manuscript.

[30] Qazwīn (Qazvīn) is one of the ancient cities of Iran which is located in 150 km northwest of Tehran.

[31] Today, Rayy (Ray or Rey) is the oldest existing city in the province of Tehran.

[32] LD: Sixth a foot less than three feet

[33] LD: Two feet and two parts

[34] LD: Two feet and a sixth

[35] LD: There is no information about the shadow lengths when the sun enters Taurus.

during the second ten days it is one foot and two parts of a foot, and during the third ten days it is one foot and a half.

And when [the sun] enters Cancer, during the first ten days [the length of one's shadow] is one foot and one third of a foot, and during the second ten days it is one foot and a half, and during the third ten days it is two feet and one sixth of a foot.

And when [the sun] enters Leo, during the first ten days [the length of one's shadow] is two feet and four quarters[36] of a foot, and during the second ten days it is three feet and one sixth[37] of a foot, and during the third ten days it is three feet and a half[38].

And when [the sun] enters Virgo, during the first ten days [the length of one's shadow] is four feet and one sixth of a foot, and during the second ten days it is four feet and four sixths of a foot, and during the third ten days it is five feet and one sixth of a foot.

And when [the sun] enters Libra, during the first ten days [the length of one's shadow] is six feet, and during the second ten days it is six feet and three fourths of a foot, and during the third ten days it is seven feet and a quarter of a foot.

And when [the sun] enters Scorpio, during the first ten days [the length of one's shadow] is eight feet and one sixth of a foot, and during the second ten days it is nine feet and one sixth[39] of a foot, and during the third ten days it is nine feet and three fourths of a foot.

And when [the sun] enters Sagittarius, during the first ten days [the length of one's shadow] is ten feet, and during the second ten days it is ten feet and four sixths of a foot, and during the third is eleven feet.

And when [the sun] enters Capricorn, during the first ten days [the length of one's shadow] is ten feet and four sixths of a foot, and during the second ten days it is ten feet, and during the third ten days it is nine feet and a half.

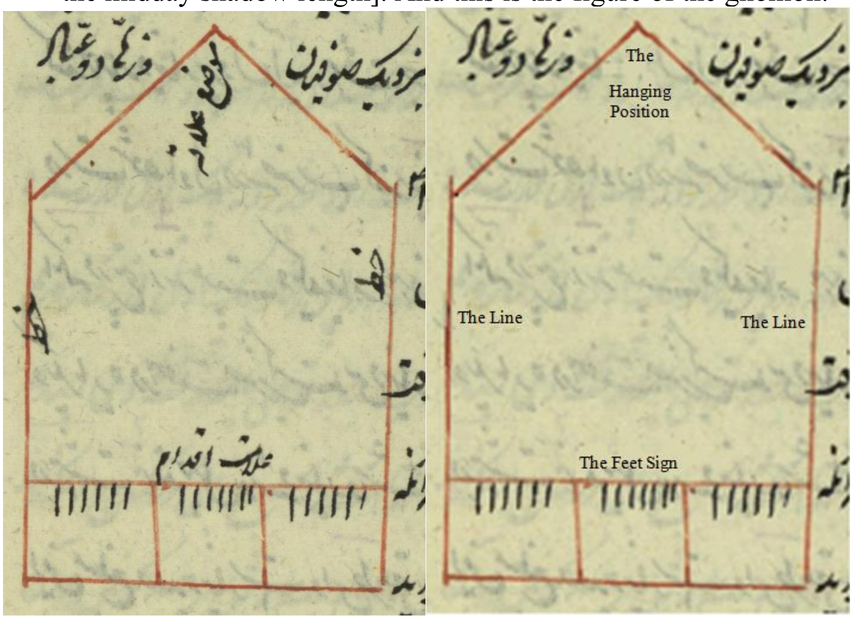
And when [the sun] enters Aquarius, during the first ten days [the length of one's shadow] is nine feet, and during the second ten days it

[36] Although this value is cited in both of our sources, it is incorrect literarily and theoretically. According to the theoretical foundations of sundials, we will use two feet and "a quarter" of a foot for our calculations in this case.
[37] LD: Three feet and a sixth and a half
[38] LD: There is no information about the third ten days
[39] LD: There is no information about the second ten days

is ten feet and three fourths [40], and during the third ten days it is nine feet and one sixth of a foot[41].

And when [the sun] enters Pisces, during the first ten days [the length of one's shadow] is seven feet and a half[42], and during the second ten days it is six feet, and during the third ten days it is five feet and a quarter.

And this is closer to the truth. And it would be better if the *muezzin* trusts a gnomon, observes its midday shadow and demarcates it daily, and determines the *ʿaṣr* prayer time [based on] seven feet beyond [to the midday shadow length]. And this is the figure of the gnomon:



[Fig. 1. A kind of gnomon which was used for determining the *ʿaṣr* prayer time by Muslims (*Yawāqīt al-ʿUlūm wa Darārī al-Nujūm*, ms. preserved in Loghatnameh Dehkhoda Institute, no. 95, f. 64 r)]

And this is famous among Sufis and pious and devout that they concern the shadow, for performing [their] prayers. The prophet Muḥammad has told: "The most devoted to God are those who love God and His devotees, and those who

[40] LD: Eight feet and a half
[41] LD: Seven feet and a half
[42] LD: Eight feet and a half

observe the sun and stars and shadows to remember God”. [The *muezzin*] has to be careful to know the *ʿaṣr* prayer time. [For this purpose, he has to] demarcate the shadow length which corresponds to the midday, then add the height of the gnomon to the midday shadow length. When the shadow length reaches to this value, it is the *ʿaṣr* prayer time. And God is the wisest as to what is correct. (This notion suffices, although the subject can be more comprehensive)

3. Commentary

A) Numerical Values of One's Shadow Length at Noon of the Beginning and Middle of Each Zodiacal Sign in the *Shāyest Nāshāyest*

As we mentioned, the values of a gnomon shadow length for determining the Zoroastrians' prayer times which are cited in the *Shāyest Nāshāyest* have similarities with some Islamic astronomical sources on this issue which were influenced by Greek and Indian background.[43] Some of the astronomical information which is cited in such sources is reckoned as folk astronomy.[44] Here we should note that since the *Shāyest Nāshāyest* is written for laity and it is not an astronomical book, the shadow lengths which are cited in this book have not been calculated, but very likely they were observed directly so it was not needed to use any mathematical device such as a sine table. A survey of the values shows that they have been rounded off to multiples of 0.50 foot. Furthermore, since we have not found any trace about a professional group, institution or work for determining Zoroastrian prayer times based on mathematical and astronomical formulae, and even nowadays it is the duty of their clergies to do it based on an oral tradition, we can refer the values which are presented in the *Shāyest Nāshāyest* to folk astronomy.

Supposing the length of a person's foot is equal to $\frac{1}{7}$ of his height[45] and on the basis of the declination of the sun, if we calculate the corresponding latitude for each shadow length which is cited in the *Shāyest Nāshāyest* by using modern mathematical methods, we find that the computed latitudes corresponding to the various shadow lengths are unequal, though it is plausible to assume that all of which were initially observed in a specific latitude. In the following, we will show that all of the computed latitudes result in a mean value equal to 31;30°.

It seems that the variation of the latitudes would be a consequence of the author's rounding off the shadow lengths.[46] In any case, it should be kept in mind that this is a religious text and is not written for astronomical, mathematical, geographical, etc. purposes, so the author would not have felt any need of highly accurate values.

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[43] King, 2004-05, vol. I, p. 476

[44] Ibid, pp. 473, 495-497, 502, 514-517

[45] al-Bīrūnī, 1948, p. 36

[46] In the following, we will show that the rounding off the values is the author's most probable method to cite them. For this purpose, we will test the interpolation method too.

B) Recomputation of the Most Compatible Values in the *S̲h̲āyest Nās̲h̲āyest*

In this section, we develop further computations to find the latitude best agreeing with the shadow lengths recorded in the text. For this purpose we have prepared a computer program which computes shadow length values for noon of the beginning and middle of each zodiacal sign during a year in different latitudes.[47] The inputs of the program are the declination of the sun (δ) and latitudes in steps of 0.1˚ from 25˚ to 40˚ (φ). For any latitude, this program computes a series of values of noon shadow lengths when the sun is at the beginning and middle of each zodiacal sign. Then, we computed the sum of differences between every calculated absolute value for a given latitude and the corresponding value in the text. Then, we chose the latitude that corresponds to the series that has minimum total difference and its values almost coincide with the values which are given in the text. Based on this computation, the values of latitudes between 31;18˚ and 31;42˚ accord with the data. So we can introduce the mean latitude (31;30˚) which best fits our values. We have also used the least mean squares method for our recomputation and it confirmed the conclusion. The southern part of Zābulistān[48] (31˚) and Yazd[49] (32˚) are two main regions lying in this range in Iran.[50] As we know, in the history of Zoroastrians, Yazd was one of their main cities and their chief temple is located near there.[51] This historical information about Yazd supports our computations.

Moreover, we then recomputed by linear interpolation to find the shadow length values, based on the shadow lengths at the equinoxes and solstices as the basic values. We used this method two times; the first time, we chose the four basic shadow length values of the text, and the second time, we chose these basic values according to the best fitted latitude. Finally we compare them with the values of the text and concluded that it is more probable that the author has rounded off the values and he didn't use the linear interpolation method.

[47]I would like to express my sincere gratitude to my dear friend Mr. Moeen Esghaei for his help in preparing this computer program.

[48] Zābulistān is a historical region based around today's Zābul province in southern Afghanistan and includes a part of today's Sīstān in Iran. Al-Bīrūnī (2002, p. 52) indicated the latitude of Zābulistān between 31˚ and 33˚.

[49] Yazd is a historical city located in central Iran. Its latitude was indicated 32˚ in medieval Islamic sources (Kennedy, 1987, p. 379) which is very close to the modern value 31;53˚.

[50] E. W. West states that the mean result derived from the calculated latitudes (based on each individual shadow length value), is in accordance with the latitude of Yazd. West, p. 399

[51] Boyce, pp. 162-164, 175

In the table 1, S_Z (F) and S_Y (F) indicate the length of one's shadow in his feet for the latitudes of the southern part of Zābulistān, and Yazd.[52] In addition, we have subtracted the values that were cited in the text from the recomputed values and shown the differences in the parentheses.

λ	S_Z (F)	S_Y (F)
0°	4.21 (-0.24)	4 (-0.50)
15°	3.35 (-0.15)	3 (-0.50)
30°	2.46 (-0.04)	3 (0.50)
45°	1.87 (-0.13)	2 (0.00)
60°	1.33 (-0.17)	1 (-0.50)
75°	1.05 (0.05)	1 (0.00)
90°	0.93 (-0.07)	1 (0.00)
105°	1.01 (0.01)	1 (0.00)
120°	1.33 (-0.17)	1 (-0.50)
135°	1.76 (-0.24)	2 (0.00)
150°	2.45 (-0.05)	3 (0.50)
165°	3.16 (-0.34)	3 (-0.50)
180°	4.18 (-0.32)	4 (-0.50)
195°	5.13 (-0.37)	5 (-0.50)
210°	6.34 (-0.16)	7 (0.50)
225°	7.45 (-0.05)	8 (0.50)

[52] For calculating these shadow lengths, we have used al-Bīrūnī's value for number of feet in one's height (7). Furthermore, choosing the value 23;26° or 24° for the declination of ecliptic doesn't affect our final results about determining the cities. Since the variation of the obliquity of the ecliptic is negligible, we can assume it as a constant equal to 23;26°. Meeus, pp. 131-136

240°	8.63 (0.13)	9 (0.50)
255°	9.42 (-0.03)	10 (0.50)
270°	9.79 (-0.21)	10 (0.00)
285°	9.52 (0.02)	10 (0.50)
300°	8.66 (0.16)	9 (0.50)
315°	7.62 (0.12)	8 (0.50)
330°	6.34 (-0.16)	6 (-0.50)
345°	5.26 (-0.24)	5 (-0.50)

Table 1. Recomputed amounts of the *Shāyest Nāshāyest* shadow length values for the southern part of Zābulistān and Yazd

In another manuscript of the *Shāyest Nāshāyest*, preserved in the Meherjirana Library (Navsari, India), some values of noon shadow lengths in the beginning and middle of zodiacal signs differ from that of the text published in Iran in 1990 (In the following, we will use "IND" for the manuscript which is preserved in the Meherjirana Library and "IR" for the text which was published in Iran). One of these differences concerns the shadow length at noon of the middle of Libra. The length of this shadow was recorded as 5 feet in IND,[53] but based on our calculations for the latitudes of Yazd and the southern part of Zābulistān the value given as 5.50 feet which appears in IR seems to be more accurate. Shadow length values written in the English translation of the *Shāyest Nāshāyest* are similar to those of IR, except for the shadow length of the beginning of Cancer.[54]

Other differences between IND and IR, relate to the shadow lengths of the middle of Capricorn and the beginning of Aquarius. In IND, these values are recorded 6.5 and 7.5 feet,[55] but in IR they are recorded as 9.5 and 8.5 feet. Moreover, in both of them, shadow lengths for the beginning of Capricorn and middle of Aquarius are recorded as 10 and 7.5 feet. But since the shadow length continuously decreases from the beginning of Capricorn to the beginning of Cancer and it is also based on the recalculated values of shadow length for Yazd

[53] *Shāyest Nāshāyest*, Meherjirana, f. 26 v
[54] Kotwal, pp. 86-88
[55] *Shāyest Nāshāyest*, Meherjirana, f. 27 r

and the southern part of Zābulistān, the two values which are recorded in IND are inaccurate.

The way the author of our text cites the shadow length values is very similar to that of Tiberius. Both of them have cited the shadow lengths for midday of the first and fifteenth degree of each zodiacal sign (of course Tiberius' text includes shadow lengths values for the morning and the ninth hour of these dates too).[56]

The Values of Shadow Length for the *Uzerīn* Prayer Time

In the next part of chapter 21, our author presents the way by which, one can determine the beginning of the *uzerīn* prayer time (from three hours after noon to the beginning of night and the appearance of stars)[57] based on the length of one's shadow.[58] According to this part, it seems that Zoroastrians determined their prayer times based on the shadow length of a gnomon (or one's shadow length) much as Muslims did.

In this part, our author has written that the values of one's shadow length at the *uzerīn* prayer time on the summer solstice, the beginning of Leo, and the winter solstice are 6 feet and "2 *bahr*s", 7.50 feet, and 14 feet and "2 *bahr*s" respectively.[59] Then, he states that from the summer solstice to the winter solstice, the shadow length increases $1\frac{1}{3}$ feet per 30 days, and 0.5 feet per 10 days, and when the sun returns to the summer solstice, shadow length decreases at the same rate.

According to the text, the difference of shadow lengths between the solstices is $14\frac{2}{3}-6\frac{2}{3}=8$. So the mean rate of increasing the shadow length is $\frac{8}{6}=\frac{4}{3}=1\frac{1}{3}$ for each month and $1\frac{1}{3}\div 3=\frac{4}{9}\cong\frac{1}{2}$ for each 10 days. However we know that on the days near the solstices, the change of the shadow length value is small. So, during the other months, the increase of the shadow length is more than on those days,

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[56] Kellogg and Sullivan, pp. 10, 11; *Shāyest Nāshāyest*, pp. 251-253

[57] Oshidari, p. 140; According to Zoroastrian clergies, the Zoroastrians' prayer times are delineated based on an oral tradition (and not mathematical or astronomical background) by their clergies.

[58] *Shāyest Nāshāyest*, pp. 252, 253

[59] In the English translations of the *Shāyest Nāshāyest* and *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm* (parts 2a. and 2b. of the present paper), "*Bahr*" was translated to "Part", but in the old Persian language "two *bahr*" was equal to $\frac{2}{3}$ (Dehkhoda, Vol. 3, p. 4439).

which compensates for this depletion. As we see, our author has recorded $7\frac{1}{2}$ feet instead of $6\frac{2}{3}+1\frac{1}{3}=8$ feet for the beginning of Leo.[60] This difference ($\frac{1}{2}$ foot) will be compensated for in the other months. Furthermore, the decrease of the shadow length is cited as $\frac{1}{3}$ feet instead of $1\frac{1}{3}$ feet for Capricorn. This difference (1 foot), too, will be compensated for in the other months. [61] In the table 2, *S* shows the values of shadow length in terms of feet for the *uzerīn* prayer time on the three days mentioned above, according to the text.

λ	$S(F)$	**Hours since noon (based on the shadow length in the text)**
90°	$6+\frac{2}{3}=6.67$	3.25
120°	7.50	3.42
270°	$14+\frac{2}{3}=14.67$	2.33

Table 2. The passed time since noon for the *uzerīn* prayer time for three important days of a year according to the *Shāyest Nāshāyest*

But, as we mentioned formerly, we know that the *uzerīn* prayer time coincides with three hours after noon, so if we recalculate those values for the best fitted latitude (31;30°), we will have three new values (table 3):

λ	$S_{31;30^{\circ}}(F)$
90°	5.97 (0.70)
120°	6.24 (-1.24)
270°	19.02 (4.35)

Table 3. Recomputed values of the shadow length for the tree *uzerīn* prayer times which are mentioned in the *Shāyest Nāshāyest*

[60] In IND, this value is written 8.50, Meherjirana, f. 27 r
[61] *Shāyest Nāshāyest*, p. 253

C) Numerical Values of One's Shadow Length in the *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm*

In this part, we shall survey the 27th chapter of another Persian text entitled *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm* which includes the values of the length of one's midday shadow for the first, second and third ten-day periods of each zodiacal sign. Since the author of this work, Abū Muḥammad al-Najjār, was adept in Islamic religious sciences and literature,[62] and based on our current knowledge, except for the *Shāyest Nāshāyest* (which is authored around the 9th c. A.D. as we mentioned formerly), there were no other Zoroastrian works including such information about determining the prayer times by shadow lengths, it is most probable that the 27th chapter of the *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm* was written influenced by other similar Islamic sources on this subject.

The framework of this text is similar to a short anonymous Syrian treatise on timekeeping.[63] There is no numerical formula in this section and its purpose is informing the laity about the prayer times, just as the *Shāyest Nāshāyest*. Moreover, as we mentioned, al-Najjār was skilled in religious sciences and literature, and not in astronomy and mathematics, so we can view it as a text in folk astronomy in its time and not a professional work on mathematical astronomy.[64]

The author believes, based on the text,[65] that the shadow lengths were observed directly in the latitude of Qazwīn (37˚) or Rayy (35;35˚) and have been rounded off to multiples of $\frac{1}{4}$ and $\frac{1}{6}$ foot.[66] We have tabulated these values and recomputed them for the mentioned latitudes. Moreover, we have also found the best fitted latitude (34;48˚) for the text values[67] and compared them with the values which correspond to the latitudes of Qazwīn and Rayy. In the table 4, S_Q

[62] Ansari, p. 329-332

[63] King, 2004-05, vol. I, pp. 508-509

[64] In this part of the mentioned book, al-Najjār tried to answer a common person who asked him how one can determine the midday [for praying] simply.

[65] *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm*, p. 242

[66] We chose the mentioned values of latitude for Qazwīn and Rayy according to *al-Qānūn al-Masʿūdī* and some other medieval Islamic sources. Al-Bīrūnī, 2002, p. 60; Kennedy, 1987, p. 270, 284

[67] For this purpose we have used the mathematical methods which are discussed in the beginning of the part B. Similar to the calculations for the *Shāyest Nāshāyest*, choosing the value 23;26˚ or 24˚ for the ecliptic declination doesn't affect our final results about determining the cities for the *Yawāqīt al-ʿUlūm*.

(F) and S_{R} (F) indicate the length of one's shadow in his feet for the latitudes of Qazwīn and Rayy.

S_{R} (F)	S_{Q} (F)	λ
4.70 (0.45)	4.95 (0.70)	0°-10°
4.08 (-0.09)	4.27 (0.10)	11°-20°
3.44 (-0.01)	3.65 (0.15)	21°-31°
2.90 (0.07)	3.10 (0.27)	32°-41°
2.49 (-0.18)	2.66 (-0.01)	42°-51°
2.11 (-0.06)	2.29 (0.12)	52°-62°
1.82 (0.15)	2.00 (0.33)	63°-72°
1.64 (-0.03)	1.81 (0.14)	73°-82°
1.54 (0.04)	1.71 (0.21)	83°-93°
1.52 (0.19)	1.71 (0.38)	94°-103°
1.60 (0.10)	1.80 (0.30)	104°-113°
1.80 (-0.37)	1.99 (-0.18)	114°-124°
2.06 (-0.19)	2.27 (0.02)	125°-134°
2.38 (-0.79)	2.65 (-0.52)	135°-143°
2.83 (-0.67)	3.12 (-0.38)	144°-155°
3.34 (-0.83)	3.66 (-0.51)	156°-165°
3.87 (-0.80)	4.25 (-0.42)	166°-175°
4.57 (-0.60)	4.95 (-0.22)	176°-186°
5.31 (-0.69)	5.74 (-0.26)	187°-196°
6.05 (-0.70)	6.57 (-0.18)	197°-206°
6.95 (-0.30)	7.48 (0.23)	207°-216°
7.86 (-0.31)	8.46 (0.29)	217°-226°
8.75 (-0.42)	9.46 (0.29)	227°-236°
9.71 (-0.04)	10.44 (0.69)	237°-246°
10.54 (0.54)	11.31 (1.31)	247°-256°
11.16 (0.49)	11.96 (1.29)	257°-266°
11.54 (0.54)	12.29 (1.29)	267°-276°
11.59 (0.92)	12.24 (1.57)	277°-286°
11.28 (1.28)	11.87 (1.87)	287°-296°
10.64 (1.14)	11.26 (1.76)	297°-306°

9.83 (0.83)	10.37 (1.37)	307˚-316˚
8.95 (0.45)	9.38 (0.88)	317˚-326˚
7.96 (0.46)	8.36 (0.86)	327˚-336˚
6.94 (-0.56)	7.38 (-0.12)	337˚-346˚
6.11 (0.11)	6.47 (0.47)	347˚-356˚
5.40 (0.15)	5.67 (0.42)	357˚-365˚

Table 4. Recomputed amounts of the *Yawāqīt al-ʿUlūm* shadow length values for Qazwīn and Rayy

As we see, the latitude that gives values closest to those of the values of shadow lengths recorded in the *Yawāqīt al-ʿUlūm*, is closer to the latitude of Rayy than to that of Qazwīn. Moreover, the differences between the interpolated values and the values written in the text show that the author did not use the interpolation method. It seems that he measured the shadow length values and rounded off them to the mentioned fractions of a foot, but his measurements were not very accurate.

After indicating the midday shadow, the author explained how the *muezzin* can determine the *ʿaṣr* prayer time. The author has also shown a figure of an instrument by which one can measure the shadow length in terms of feet for determining the *ʿaṣr* prayer time (Fig. 1). Unfortunately the author didn't explain how to use it, but it seems that one should hang it from its top which is indicated by the name "Hanging Position" (*Mowḍiʿi ʿAlāqeh*) and use the graduated scale at the bottom, for measuring the shadow lengths. Presenting the picture of this instrument in the text, makes it more likely that the shadow lengths were written based on direct observations and not on calculations.

4. Conclusions

A survey of the two mentioned texts shows some similarities between their frameworks, both of which have two main parts, the first being allocated to the values of midday shadow lengths to determine the *ẓuhr* (*rapīthwan*) prayer time, and the latter showing how to determine the *ʿaṣr* (*uzerīn*) prayer time. Another similarity is that both texts show a strong religious interest and so the values that are cited by their authors are not so accurate as would be required in an astronomical work. Thus, the values presented in the both works belong to the tradition of folk astronomy.

Al-Bīrūnī's reference to a part of *S̲h̲āh Zīj*, which is related to the use of a gnomon for determining some solar parameters, demonstrates that the Sassanid astronomers knew how to use a gnomon for some sophisticated astronomical purposes such as timekeeping. Hence, citation of the values of midday length of one's shadow in a chapter of a Zoroastrian religious book whose main parts were written in the Sassanid era is not surprising.

According to the 21st chapter of the *S̲h̲āyest Nās̲h̲āyest*, we can conclude that Zoroastrians, like Muslims, used the shadow length of gnomon for determining their prayer times. And, on the basis of this Zoroastrian text, there is a similarity between the Zoroastrian and Muslim methods of determining the daily prayer times. But since we don't know whether this chapter was included in main parts of the book, we do not claim that the use of a gnomon for determining prayer times was in common in pre-Islamic Iran. Furthermore, we have to take account of one Indian source, inspired by Mesopotamian astronomy, which includes the values of midday shadow length of a gnomon for measuring the time. In fact in the lands around Iran it seems there was a custom of timekeeping which is very similar to the way that is used in the *S̲h̲āyest Nās̲h̲āyest*, and various Islamic sources such as *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm*, *Aḥsan al-Taqāsīm* and *al-Mug̲h̲nī*. All of these things lead us to conclude that it is quite possible the 21st chapter of the *S̲h̲āyest Nās̲h̲āyest* was written under the Islamic domination in Iran, and that Zoroastrians were inspired by Muslims to use the shadow length of a gnomon for determining their prayer times, which were also influenced by Muslims.

Finally, our calculations and corrections for the sizes of shadow lengths which were written in the *S̲h̲āyest Nās̲h̲āyest*, shows that the original table was composed for a latitude between 31;18° and 31;42°. The most likely regions in Iran are therefore, the southern part of Zābulistān (31°) and Yazd (32°). On the basis of the historical information we have about Zoroastrians, it is more probable that the city was Yazd. In addition, the latitude (34;48°) yielding results that best fit the values of shadow lengths that are cited in the *Yawāqīt al-ʿUlūm* *wa Darārī al-Nujūm.* Though the author of this book wrote that the values correspond to the latitudes of the cities Rayy and Qazwīn, our calculations show that the values accord more closely with the latitude of Rayy (35;35˚) rather than that of Qazwīn (37˚). It is noteworthy that for finding the closest cities to the best fitted latitudes in both cases, we used medieval values of the latitudes. We have also corrected some errors in the shadow lengths cited by the authors.

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Appendix

a. Original Text of the *Shāyest Nāshāyest* (*Shāyest Nāshāyest,* Mazdapour, pp. 251-253)

21

1. Nišān ī sāyag ī nēm-rōz nibēsēm, farrox bawād!

2. Xwaršēd pad karzang, panĵ-ēk <ī>, pāy ī mard; pānzdahom ī karzang, ēk pāy; xwaršēd pad šēr, ēk pāy ud nēm; pānzdahom ī šēr, dō pāy; xwaršēd pad hōšag, dō pāy ud nēm; pānzdahom ī hōšag, se pāy ud nēm; tarāzug, čahār pāy ud nēm; pānzdahom ī tarāzug, panĵ pāy ud nēm; gazdum, šaš pāy ud nēm; pānzdahom ī gazdum, haft pāy ud nēm; nēmasp, hašt pāy ud nēm; pānzdahom ī nēmasp, nō pāy ud nēm; wahīg, dah pāy, pānzdahom ī wahīg, nō pāy ud nēm; dōl, hašt pāy ud nēm, pānzdahom ī dōl, haft pāy ud nēm; māhig, šaš pāy ud nēm, pānzdahom ī māhig, panĵ pāy ud nēm; warrag, čahār pāy ud nēm; pānzdahom ī warrag, se pāy ud nēm; gāw, dō pāy ud nēm; pānzdahom ī gāw, dō pāy; dō-pahīkar, ē pāy ud nēm; pānzdahom ī dō-pahīkar, ē pāy.

Sāyag ī nēm-rōz wašt, xūb-frazām bawād!

3. Nišān ī uzērin nibēsēm, xūb ud farrox bawād; pad yazadān ayārīh!

4. Ka rōz pad abzōn bawēd, xwaršēd pad sar ī karzang āyēd ud sāyag šaš pāy ud dō bahr bawēd; uzērin gāh gīrēd.

5. Har sīh rōz-ē pāy-ē ud se ēk-ē hamē abzāyēd, nūn čiyōn hard ah rōz, nēm pāy ōšmār hamē bawēd; xwaršēd pad sar ī sēr, sāyag haft pāy ud nēm.

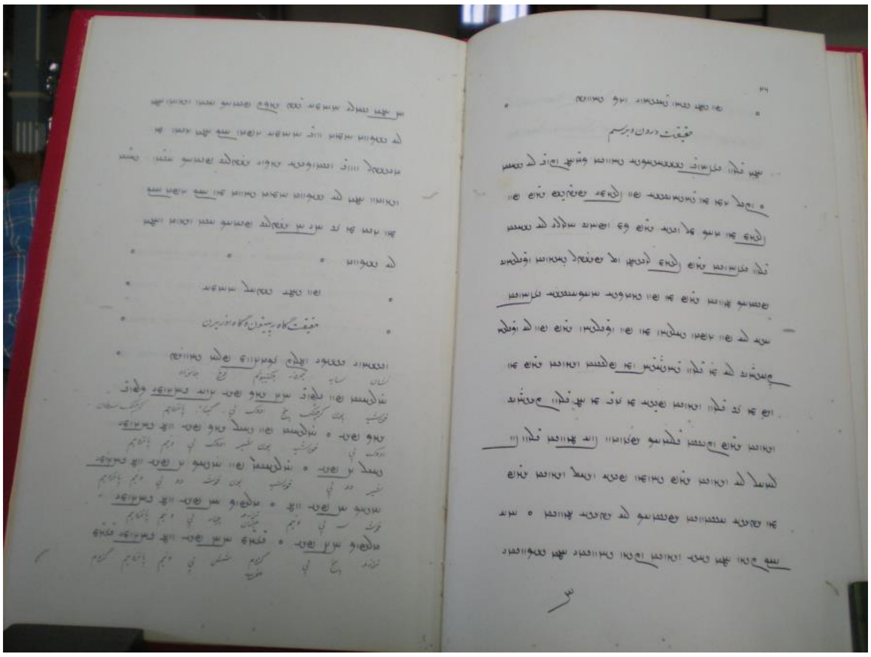
6. Pad ēn padisār, har axtar-ē ham-gōnag, ud māhīgān ham-gōnag; tā xwaršēd be sar ī wahīg āyēd, sāyag čahārdah pāy ud dō bahr bawēd.

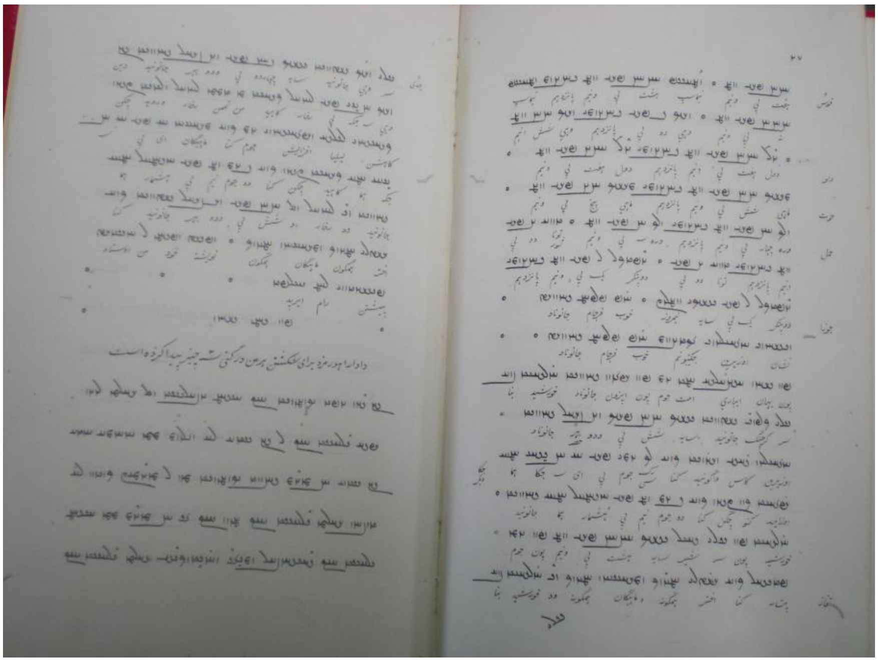
7. Andar wahīg, se ēk ī pāy abāz kāhēd, az anōh abāz wardēd, čiyōn kāhišn ī šab ud abzāyišn ī rōz. har māhīgān-ē pāy-ē se ēk-ē hamē kāhēd, čiyōn har dah rōz, nēm pāy ōšmār hamē bawēd; tā abaz ō šaš pāy ud dō bahr āyēd. har axtar-ē ham-gōnag ud māhīgān ham-gōnag.

8. a. Nibišt ud frazāmēnīd hēm, man dēn-bandag mihr-āban ī kay-husraw hērbed-zād.

8. b. Nibišt xwēš man awestād pešyōtan ī rām, hērbed.

b. A Manuscript of the ***S͟hāyest Nās͟hāyest*** Preserved in the Meherjirana Library (Navsari, India), no. 3.3





c. Original Text of the *Yawāqīt al-ʿUlūm wa Darārī al-Nujūm* (*Yawāqīt al-ʿUlūm wa Darārī al-Nujūm*, Mohammad-Taqi Daneshpazhooh, pp. 242-244)

مسئلهٔ یب: شناختن زوال آفتاب به اقدام چگونه باشد؟

جواب: زوال آفتاب به زیادت سایهٔ اشخاص بدانند. و آن، چنان باشد که چوبی راست به زمین فرو برند تا چون آفتاب برآید سایه از سر چوب سوی مغرب افتد دراز. آنگاه چنانکه آفتاب بر می‌آید آن سایه می‌کاهد و از سوی مغرب می‌گردد، تا آنگاه که آفتاب به غایت ارتفاع خویش رسد سایه وقفه کند. آنگاه دیگرباره در زیادت افتد. آن لحظه که زیادت سایه در توان یافتن، وقت زوال باشد. و در علم خدای تعالی آفتاب پیش از آن زوال خود کرده بود، ولیکن خطاب شرعی آنگاه متوجه شود که محسوس گردد. و اما قدر سایه در ازمان و بلدان بگردد. و غایت طول سایه در عرض قزوین و ری یازده قدم باشد. اما مثال چنان بود که چون آفتاب به حمل آید در عشر اول چهار قدم و چهار یک از قدم بگردد، و در عشر دوم بر چهار قدم و شش یک از قدم بگردد، و در عشر سوم بر سه قدم و نیم بگردد.

و چون به ثور آید در عشر اول بر سه قدم کم شش یکی از قدم بگردد، و در عشر دوم بر دو قدم و دو بهر از قدم بگردد، و در عشر سوم بر دو قدم و شش یک از قدم بگردد.

و چون به جوزا آید در عشر اول بر یک قدم و چهار شش از یک قدم بگردد، و در عشر دوم بر قدمی و دو بهر از قدمی بگردد، و در عشر سوم بر قدم و نیم بگردد.

و چون به سرطان آید در عشر اول بر یک قدم و سه یک از قدمی بگردد، و در عشر دوم بر یک قدم و نیم بگردد، و در عشر سوم بر دو قدم و شش یک از قدمی بگردد.

و چون به اسد آید درعشر اول بر دو قدم و چهار ربع از قدمی بگردد، و در عشر دوم بر سه قدم و سدس قدمی بگردد، و در عشر سوم بر سه قدم و نیم بگردد.

و چون به سنبله آید در عشر اول بر چهار قدم و سدس قدمی بگردد، و در عشر دوم به چهار قدم و چهار سدس قدمی بگردد، و در عشر سوم به پنج قدم و سدس قدمی بگردد.

و چون به میزان آید در عشر اول بر شش قدم بگردد، و در عشر دوم بر شش قدم و سه ربع از قدمی بگردد، و در عشر سوم هفت قدم و ربع قدمی بگردد.

و چون به عقرب آید در عشر اول به هشت قدم و سدس قدمی بگردد، و در عشر دوم بر نه قدم و سدس قدمی بگردد، و در عشر سوم بر نه قدم و سه ربع قدمی بگردد.

و چون به قوس آید در عشر اول به ده قدم بگردد، و در عشر دوم به ده قدم و چهار سدس قدمی بگردد، و در عشر سوم به یازده قدم بگردد.

و چون به جدی آید در عشر اول به ده قدم و چهار سدس قدمی بگردد، و در عشر دوم به ده قدم بگردد، و در عشر سوم به نه قدم و نیم بگردد.

و چون به دلو آید در عشر اول به نه قدم بگردد، و در عشر دوم به ده قدم و سه ربع بگردد، و در عشر سوم به نه قدم و سدس قدمی بگردد.

و چون به حوت آید در عشر اول به هفت قدم و نیم بگردد، و در عشر دوم به شش قدم بگردد، و در عشر سوم به پنج قدم و ربعی بگردد.

و این به تحقیق نزدیک‌تر است. و آن بهتر باشد که مؤذن چون مقیاس معتمد دارد روز به روز سایهٔ زوال می‌گیرد و نشان می‌کند و نماز دیگر بر آن حساب می‌کند بعد هفت قدم و صورت مقیاس این است:

[Fig. 1.]

و این مشهور است نزدیک صوفیان و زهاد و عباد که بدان مراعات سایه کنند برای اوقات نماز و عبادات. مصطفی صلی الله علیه و سلم می‌فرماید: «خیار عبادالله الذین یحبون الله ویحبون الی عباده

والذین یراعون الشمس والنجوم والاظلة لذکر الله تعالی» در معرفت وقت نماز دیگر نیک احتیاط کند. آن سایه که آفتاب بر وی زوال کرده باشد نشان کند، آنگاه به مقدار بالای آن چوب که سایه افکنده است بر سر آن سایه زوال آن روز افزاید. چون سایه اینجا رسد، وقت نماز دیگر باشد. والله اعلم بالصواب. [این معنی در این فن بسنده کنیم هرچند سخن درازتر می‌شود.]