

The Islamic Prayer Times – Computational Philosophy with Particular Reference to the Lack of Twilight Cessation at Higher Latitudes

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INTRODUCTION

The knowledge of the starting and ending times for prayers is of fundamental importance to Muslims. One of the requirements of offering prayers is the correct time interval in which they ought to be offered. The prayer and fasting times which Prophet Muhammad (peace be upon him), in accordance with Almighty Allah's commands, have established are primarily dependent upon observation.

The objective of this article is to provide:

- (1) A rational approach based on "Shariah" and "Fiqha", for the calculation of prayer and Sahur times.
- (2) A lucid account of the twilight phenomenon (Subha-Sadeq) and the problems associated with its continuity throughout the 24-hour period during the summer months at high latitude locations. This phenomenon is observed, without any cessation, within the terrestrial belt covering the latitudes of 48.5°N and 48.5°S.
- (3) A discussions of the alternative solutions, based on jurisprudence (Fiqha), for the Sahur/Fajr/Isha times for higher latitudes, i.e. latitudes in excess of 48.5°.

DEFINITIONS AND ANALYSIS

In the following sections, a brief introduction to the calculation procedure will be provided.

Equation of Time

The earth revolves around the sun in a slightly elliptical orbit with the earth-sun distance being 89.8 million miles on December 21st and 95.9 million miles on June 21st.

The earth's orbital velocity varies throughout the year, and so Apparent Solar Time (AST), as determined by a sundial, varies slightly from the mean time kept by a clock running at a uniform rate. This variation is called the Equation of Time (ET).

The Equation of Time varies cyclically over a year – though strictly speaking, its variation is better represented by a four-year cycle.

The sun's position in the sky is obtained by AST, found by adding the ET to the local Standard Time (LST) along with the longitude correction:

$$AST = LST + ET + (LON - LSM) / 15 \quad (1)$$

In the above equation, LON is the local longitude and LSM is the longitude of the Standard Time Meridian. For the United Kingdom, Saudi Arabia, Pakistan, and India LSM respectively assumes a value of 0°, 45°, 75° and 82.5°.

The day-to-day value of ET may be obtained from the American Ephemeris and Nautical Almanac published by the Nautical Office of the US Naval observatory. For computer use, the monographs by Muneer (1997) and Muneer (2000) provide the highly accurate Yallop algorithm for ET in hard- and soft-formats.

Solar Declination

The earth's equatorial plane is tilted at an angle of 23.5° to the orbital plane, the solar declination DEC, the angle between the earth-sun line and the equatorial plane, varies throughout the year. This variation of the solar declination causes the changing seasons, with their unequal periods of daylight and darkness.

When the solar declination is positive, implying that the Northern Hemisphere is facing the sun, the day will be longer than night and vice-versa.

For computer use, the monographs by Muneer (1997) and Muneer (2000) provide the highly accurate Yallop algorithm for DEC in hard- and soft-formats.

Astronomical Sunrise and Sunset

Astronomers define the sunrise or sunset as the moment at which the centre of the sun is along the horizon of the earth. The position of the sun at any instant is fixed by two quantities, the sun's altitude above the horizon and its azimuth (the angle between the south and the projection of sun on earth's surface). The sun's altitude (α) is dependent upon three quantities, the Latitude (L) of the location, the solar declination and Apparent Solar Time,

$$\sin \alpha = \cos L * \cos DEC * \cos W + \sin L * \sin DEC \quad (2)$$

$$W = 15 * (12 - \text{AST})$$

According to the definition, the altitude will be zero at astronomical sunrise. Hence,

$$\cos W = -\tan L * \tan DEC \quad (3)$$

will provide the time corresponding to the astronomical sunrise event.

Actual Sunrise and Sunset

The actual sunrise and sunset do not occur at the time when the sun's elevation is zero. This is due to the refraction of light by terrestrial atmosphere. A ray of light travelling in vacuum from a sun which is actually below the earth's horizon is bent towards the earth by the heavier medium, air (the average refractive index of atmospheric air is 1.000 3). Hence actual sunrise appears slightly before astronomical sunrise and actual sunset occurs after astronomical sunset. Further, for locations which are higher than the sea level, the sun will appear in the morning slightly earlier. Corrections have therefore to be made for the above refraction and altitude effects. These are expressed via Equation 4 for α which refers to the instance of actual sunrise or sunset.

$$\alpha = -0.8333 - 0.0347 H^{0.5} \quad (4)$$

H in the above equation is to be given in metres above sea level (m.a.s.l). Equation 2 is then solved in conjunction with Equation 1 to obtain the corresponding local civil time.

Dawn and Dusk

Dawn is that moment when the reflected and refracted rays from the sun begin to reach the earth. Dawn happens much in advance of the actual sunrise. In the very beginning, a vertical white streak of light appears above the horizon and as the sun approaches, the rays of the light change their direction and begin to spread over the horizon. Then with further approach of the sun, the refracted rays also appear with the result that the intensity of the light increase and the colour changes from white to pinkish and then to yellowish. The sunrise follows this moment.

Dusk is that moment when diffuse light is present over the western horizon after the sun has set. The change of colour at dusk is in the reverse order of dawn. It has been demonstrated via measurements of twilight intensity that the time of dawn and dusk are those moments when the sun is 18° below the horizon.

Thus the calculation of the time of dawn and twilight may be obtained by use of Equation 2 by using the value of $\alpha = -18^\circ$.

Noon Shadow

Noon shadow is the shadow of a vertical pole at the exact solar noon. Solar noon is the time when the Apparent Solar Time is 1200 hours or when the sun has the highest altitude. Sometime the noon shadow is also called as the true shadow or declining shadow.

Note that in latitude north of the Tropic of Cancer and south of the Tropic of Capricorn, the sun never reaches 'overhead', i.e. α is always less than 90° .

The way to estimate the noon shadow is as follows:

Refer to Equation 2. At solar noon $W = 0$, hence,

$$\sin \alpha = \cos L * \cos DEC + \sin L * \sin DEC$$

$$\sin \alpha = \cos (L - DEC)$$

$$\alpha = 90 - (L - DEC)$$

Assuming the height of the vertical pole to be unity, the noon shadow will then be $= \cot (DEC)$.

Shadow Lengths

When the shadow of a vertical pole is equal the height of the plus the noon shadow, it is termed as 'same-sized' and when the shadow's length is twice the height of the pole plus the noon shadow, it is term as 'double-sized' shadow.

Twilight

Twilight is defined as the pre-sunrise or post-sunset period of partial daylight and is caused by the reflection and scattering of sunlight towards the horizon of any terrestrial observer. Twilight has an important biological and socio-religious significance. At any one instant, the twilight zone covers 20-25% surface area of our Globe and humans, on an average, live under the twilight band for a quarter of the time. In the tropics, due to the sun's steep descent towards the horizon, twilight occupies only 10-15% of the diurnal cycle. However, in the higher latitudes such as those of Northern Europe, twilight occupies up to two-fifths of the annual cycle.

Soon after the sunset the illuminance progressively diminishes in an exponential manner until the sun sinks to an elevation angle of -18 degrees. This is the instance of the last stage of receipt of light emanating from the sun (astronomical twilight). The negative elevation angle, which corresponds to the period of twilight, is also expressed as the angle of depression. Thus, when $\alpha = -18$ degrees, the depression angle = 18 degrees.

Various stages of twilight have been standardised, e.g. civil and nautical twilight, respectively, when the solar depression angles are 6 degrees and 12 degrees. Civil twilight is the stage when enough illuminance exists to enable outdoor civil activity to continue unhindered without resorting to the use of electric street lighting. The nautical twilight is the stage which establishes the limit of the visibility of ships approaching a harbour.

The following illuminance figures for the above three stages of twilight have been reported by Muneer (1997). For a horizontal surface under a cloudless sky,

sun at zenith:	103,000	lux
sun at horizon:	355	lux
end of civil twilight:	4.3	lux
end of astronomical twilight:	0.001	lux
full moon at zenith:	0.215	lux

It is with some fascination we note that the change in illuminance from noon to astronomical twilight is around 100 million! Even between the sunset to the end of twilight instance the change is about 400,000. Yet the human eye being a logarithmic sensor is able to cope with such wide-ranging illuminance levels. Laboratory measurements of daylight and twilight are undertaken with sensors which operate in much narrower ranges.

An exhaustive review of the research undertaken on twilight phenomenon and its measurement has been presented by Rozenberg (1966). Qasmi and Muneer (1990) have explored the variation of midnight solar depression angle for three high latitude locations. Several interesting points have been deduced by them. Firstly they have noted that for a location at 60°N - e.g. Lerwick, the minimum depression angle is only 6° in June. Hence, in such locations the minimum twilight intensity will correspond to civil twilight. This phenomenon has been confirmed by actual observations. For

example, it is reported that the people in Lerwick are able to read newspaper under the midnight sky during the peak summer months.

Secondly, the minimum solar depression for Glasgow is about 10.7° . Hence for a period in summer, the midnight twilight intensity exceeds the nautical twilight limit. It may be pointed out that the nautical twilight corresponds to a solar depression of 12° .

Thirdly, although the midnight solar depression for London is less than 18° (astronomical twilight limit), the depression is always in excess of 15° which is the observed lower limit for the 'reddening' of the sky.

Thus, in London, it is possible to pray Isha throughout the year as dictated by the Shawafi jurists! Of course it will not be possible to observe Hanafi Principle for Isha during peak summer period owing to the fact that the astronomical twilight will be ceaseless.

In the above paragraphs it was shown that the last trace of daylight is received on the earth's surface at the end of astronomical twilight and this corresponds to the depression of sun below the horizon being 18° . According to Imam Abu Hanifa (R.A.A.) the time for Isha prayer begins at the end of this twilight. The time for Sahur ends and that for Fajr starts at the beginning of this twilight in the early morning hours.

The question which arises at this stage is that during those months in which there is not true night-twilight extending from sunrise to sunset-what should be the criterion to determine the beginning of Isha and Fajr times, or what should be the limiting time for Sahur? In this respect we quote here what Molvi Qasmi says in his book "the true time of twilight in Britain". He writes ".....it should be understood that in the absence of any guide line provided by our Prophet (peace be upon him), the principle adopted in light of the judgement of the followers of the early jurisprudentia and the latter jurists will be approximate and not absolute". However for the higher latitudes since the occurrence of true night does not happen in a period during the summer months a solution, although it may be approximate, has to be sought.

The following solutions are available for this "abnormal" period.

1 "Nearest Day" (Aqrab Al-Ayyam)

This principle is due to the following jurists of the Hanafi school. The principle is, for those places where during a period of time the twilight does not end, the time for Sahur for this "abnormal" period will be taken as the time for the last day on which twilight ended. For example in Aberdeen the last day on which twilight ends in the night and then begins in the morning (at 1.20 am) is 30th April. Hence throughout the abnormal period (1st May to 12th August) the limit time for Sahur will remain at 1.20 am.

2 "Nearest Latitude" (Aqrab Al-Balad)

This principle is due to the fellow jurists of the Shafi school. The difference of time between the beginning of twilight and sunrise at 48^o latitude is calculated. The same difference is maintained between the end of Sahur time and the sunrise for the locality for which the Sahur time is to be evaluated.

3 Middle of the Night (Nisf Al-Lail)

This principle is due to the latter jurists. The period from sunset to sunrise is divided into two halves. The first half is considered to be the "night" and the other half as "day break". Thus the time for Sahur will end at the mid-point.

4 "One-seventh of the Night" (Sabe Min-Lail)

This principle is again attributed to recent jurists. The period between sunset and sunrise is divided into seven parts. During the six-seventh of the period, following sunrise, it is recommended that people may consume food for Sahur. The time limit for Sahur will therefore be one-seventh part of the night, before sunrise. For example on 6th May in Aberdeen the sunset time is 9.04 pm and sunrise on the following day is 5.04am. The sunset to sunrise

duration is therefore 480 minutes. One-seventh of this duration is approximately 69 minutes. Thus the limit time for Sahur on 7th May will be 3.55 am.

It must be borne in mind that during the “abnormal” period there is room in the jurisprudence to follow anyone of the four principles cited above to determine the limit time for Sahur and initiation time for Fajr. In the following section the basis for estimation of prayer times will be described.

END OF SAHUR/FAJR TIME

As it has been discussed above, this is the most ambiguous of all prayer times owing to the absence of true night in the higher latitudes. Thus for any locality for which a yearly calender of prayer and Sahur times ahs to be made, the first step is to find out the “ normal” period and the “abnormal” period. (refer to Table 2).

During the “normal” period (the days in which sun sinks 18° below the horizon after sun set and then appears 18° below the horizon before the sunrise) the time for end of Sahur is the time at which astronomical twilight appears. However, during the “abnormal” period, any one of the four solution highlighted above may be adopted.

Prayer times for zones of extreme abnormality – The Arctic and Antarctic Circles

This section provides a discussion on the hypothetical question of the solution for prayer times for zones of extreme abnormality, i.e. the Arctic and Antarctic Circles (latitude in excess of 66.5 degree). Table 3 shows that as one approaches the poles, the period of no sunset (or indeed sunrise) increases in duration. Molvi Y I Qasmi has once again provided a discussion on this subject in light of the famous ‘Dajjal’ related Hadith. The solution in this case in ‘Aqrab Al-Balad’. The highest latitude at which all the five prayer times may be offered in accordance with the rules set out in the Shariah is 48.5 degree. Thus, one would use the prayer schedule for the latter latitude, both for offering salat and start/end of the fasting period.

Note that Table 3 was produced using the relationship $\tan LAT = \cot DEC$ which enables determination of the period of no sunset.

References

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Table 1 Duration of astronomical twilight

Latitude	Equator		50 N		60 N	
	H	m	h	m	h	m
<i>Winter Solstice(Dec 21)</i>	1	15	2	01	2	48
<i>Equinox(March 21&Sep 21)</i>	1	10	1	52	2	31
<i>Summer solstice(June 21)</i>	1	15	-----		-----	

Table 2 Days without true night - Twilight extending from sunset to sunrise

<i>North Latitude (Deg)</i>	<i>Period of no true night</i>
50	11 June - 1 July
51	25 May - 17 July
52	21 May - 24 July
53	15 May - 27 July
54	13 May - 31 July
55	9 May - 3 August
56	5 May - 9 August
57	1 May - 11 August
58	29 April - 15 August
59	25 April - 17 August
60	21 April - 24 August

Table 3 Annual duration when the sun does not set: Arctic circle

Latitude	DEC		Duration
	Degree	Minute	
66.5	23	26	Jun 20-23
71.5	18	30	May 14 - Jul 30
76.5	13	30	Apr 27 - Aug 17
81.5	8	30	Apr 12 - Aug 31
86.5	3	30	Mar 30 - Sep 14
90.0	0	0	Mar 21 - Sep 21