Islamic lunar calendar and prayer times

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Cover photo: The Earth and Moon imaged by Mariner 10 from 2.6 million km while completing the first ever Earth-Moon encounter by a spacecraft capable of returning digital colour images.
Image Credit: NASA/JPL/Northwestern University, USA

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The sun and moon follow courses (exactly) computed. Holy Quran (55:5)

1. INTRODUCTION TO ISLAMIC LUNAR CALENDAR

Astronomy has been called the queen of sciences for a very valid reason. It encompasses the arts and sciences under the domain of mathematics, physics, chemistry and thermodynamics. Since time immemorial man has wondered about the nature and motion of stars and planets. For this reason he has conducted scholarship in the astronomical sciences with a vigour which has no match to his activities in other disciplines. This deep rooted interest of man in astronomy is perhaps understandable owing to the necessity man has felt towards logging of time.

With the dawn of Islam astronomy acquired a genuine researcher in the form of the Muslim. The determination of precise prayer times and the direction of Makkah (Qibla) were required for new locations with the rapid spread of Islam. This effort of the early Muslim astronomers has been duly acknowledged.

Astronomy presented a special challenge to the Muslims. It was necessary to master and further develop the field of astronomy to meet the daily needs of the faithful. "Yaqub Ibn Tariq, Alkhwarizmi, Albattani, Alfarghani, Alsoofi, Alberuni, Altoosi and Omar Khayyam these are a few of the many Muslim astronomers whose work has influenced the present day developments", thus writes a historian of science [Extract from M A Anees in 'Lunar horizons: Inquiry journal p. 69, volume 2, number 2, 1984]. Another historian observes thus, "Mohammed (peace be upon him), as we have noted, was an unlettered man; he may never have been able to read a book but he had the highest respect for knowledge. 'The ink of the scholar is more holy than the blood of the martyrs', runs one hadith, and another, 'He who leaves home in search of knowledge walks in the path of Allah'. A third is more explicit: 'Knowledge is our friend in the desert, our society in solitude, our companion when bereft of friends; it guides us to happiness, it sustains us in misery, it serves as armour against enemies'. In the light of such encouragement, Muslims devoted themselves to study and teaching with marked success. As a people, the Arabs were as unlettered as their Prophet; but they had the gift of learning from their subjects, and throughout the Middle Ages the Muslim universities and schools were far ahead of those in Christendom. Unlike the Christians, the Muslims were generally tolerant, and astronomy and other sciences were able to make progress unhampered by theological opposition" [Extract from E R Pike, 'Mohammed: Founder of the Islamic Religion, Weidenfeld & Nicholson Educational Limited, London 1962 as quoted by M Ilyas in 'Astronomy of the Islamic Times for the 21st Century', Mansell Publishing Limited, London 1988].

Text box 1 provides a synopsis of the Muslim contribution to astronomy and mathematics.

Mohammed Ilyas has provided an interesting survey of the number of astronomy related manuscripts published between the dawn of Islam and the mid-fifteenth century [A Modern Guide to Astronomical Calculations of Islamic Calendar, Times & Qibla-Berita Publishing, Kuala Lampur -1984]. Ilyas has shown that of a total of 127 authors who contributed towards the development of the subject, 120 were Muslim scholars (95 % of the total contributors), 4 were Christians and 3 of Jewish faith. This should not come as a surprise as the Holy Scripture Quran has provided numerous prompts towards astronomy:

"It is He who made the sun to be a shining glory and the moon to be a light (of beauty), and measured out Stages for her that ye might Know the number of years and the count (of time). Nowise did Allah create this But in truth and righteousness. (Thus) doth He explain His Signs In detail, for those who understand" (Sura Yunus, Verse 5).

This booklet has been compiled with a view to provide an account of the astronomical conditions required for the earliest moonsighting. An in-depth treatment of the subject has been deliberately avoided. Readers interested in further details may refer to M Ilyas' treatise referred above "A Modem Guide to Astronomical Calculations of Islamic Calendar, Times & Qibla" or the NAO Technical Note No. 69 issued by the HM Nautical Almanac Office (Royal Greenwich Observatory), Cambridge, UK. The well-known astronomer Dr B D Yallop produced the latter note. A fuller recommended reading list is also appended.

It is a sincere hope that this book will be of some value towards educating and uniting the Muslim Ummah. May Allah through His Immense Graciousness and Mercy accept this work and induce in us the fervour, which was the hallmark of the earlier Muslims.

Text box 1 Muslims contribution to Astronomy and Mathematics

General: The Arabs were pioneers within the fields of Astronomy, Mehanics, Mathematics, Algebra, Statics and Conic Section. In Geometry the Muslims were the first to translate Euclid's work. They developed the theory of quadratic equations and binomial theorem. Muslim astronomers identified and classified a large number of stars in their observatories. They made discoveries regarding the movements of the Solar system and other astral bodies. They ascertained the size of the earth, the variation of lunar latitudes and its precession of the equinoxes. Muslims built the first observatories and invented the telescope, the compass and the pendulum. The Arabic numerals, transmitted by Arabs to Europe from the Indian system, gave a great impetus to learning.

- Averroes (Ibn-Rushd): Discovery of sun-spots.
- Al-Hazan: Discovery of atmospheric reflection and refraction.
- Al-Maimun: Discovery of the obliquity of the ecliptic.
- Nasiruddin Tusi, Muhammad Farghani and Albani: Construction of atronomical tables. These tables were later translated in Latin and formed the basis of astronomical study within Europe.
- 'Khizanat al-Hikma' (Library of Wisdom) established by Caliph Haroon al-Rashid in Baghdad during 786-209 CE. This library undertook the task of translating large volumes of Greek manuscripts in Arabic.
- 'Bayt al-Hikma' (House of Wisdom) founded by Al-Mamun in Baghdad. This academy continued the work of translation of books to Arabic and also established two major observatories, one in Baghdad and the other in Damascus.
- Between 909 and 1171 CE, the Fatimids developed 'Dar al-Hikma' (House of Science), a large library and conference centre in Cairo. This facility provided a base for conduct of seminars and exchange of scientific information.
- Ulugh Beg: Established world's first major observatory at Samarkand in 15th century CE.
- Taqi al-Din: Established a major observatory at Istanbul in 16th century CE.

References: A Y al-Hassan and D R Hill, Islamic technology: An illustrated history. Cambridge University Press, Cambridge, 1992 & M A Karim, A simple guide to Islam's contribution to science and civilisation. Goodword books, Delhi, 2003.

2. SELECTED QURANIC VERSES RELATED TO THE SOLAR AND LUNAR BODIES

The sun and moon follow courses (exactly) computed. 55: 5

Verily, the number of months with Allâh is twelve months (in a year), so was it ordained by Allâh on the Day when He created the heavens and the earth; of them four are Sacred, (i.e. the 1st, the 7th, the 11th and the 12th months of the Islâmic calendar). That is the right religion, so wrong not yourselves therein, and fight against the Mushrikûn (polytheists, pagans, idolaters, disbelievers in the Oneness of Allâh) collectively, as they fight against you collectively. But know that Allâh is with those who are Al-Muttaqûn. 9: 36

They ask you (O Muhammad SAW) about the Hilaal. State: These are signs to mark fixed periods of time for mankind and for the pilgrimage. It is not Al-Birr (piety, righteousness, etc.) that you enter the houses from the back but Al-Birr (is the quality of the one) who fears Allâh. So enter houses through their proper doors, and fear Allâh that you may be successful. 2: 189

He is the Cleaver of the Daybreak, and He hath appointed the night for stillness, and the sun and the moon for reckoning. That is the measuring of the Mighty, the Wise. 6: 96

Lo! your Lord is Allah Who created the heavens and the earth in six Days, then mounted He the Throne. He covereth the night with the day, which is in haste to follow it, and hath made the sun and the moon and the stars subservient by His command. His verily is all creation and commandment Blessed be Allah, the Lord of the Worlds! 7: 54

He it is who appointed the sun a splendour and the moon a light, and measured for her stages, that ye might know the number of the years, and the reckoning. Allah created not (all) that save in truth. He detaileth the revelations for people who have knowledge. 10: 5

Allah it is who raised up the heavens without visible supports, then mounted the Throne, and compelled the sun and the moon to be of service, each runneth unto an appointed term; He ordereth the course; He detaileth the revelations, that haply ye may be certain of the meeting with your Lord. 13: 2

And maketh the sun and the moon, constant in their courses, to be of service unto you, and hath made of service unto you the night and the day. 14: 33

And he hath constrained the night and the day and the sun and the moon to be of service unto you, and the stars are made subservient by His command. Lo! herein indeed are portents for people who have sense. 16: 12

Establish worship at the going down of the sun until the dark of night, and (the recital of) the Qur'an at dawn. Lo! (the recital of) the Qur'an at dawn is ever witnessed. 17: 78

And He it is Who created the night and the day, and the sun and the moon. They float, each in an orbit. 21: 33

Hast thou not seen how Allah causeth the night to pass into the day and causeth the day to pass into the night, and hath subdued the sun and the moon (to do their work), each running unto an appointed term; and that Allah is Informed of what ye do? 31: 29

He maketh the night to pass into the day and He maketh the day to pass into the night. He hath subdued the sun and moon to service. Each runneth unto an appointed term. Such is Allah, your lord; His is the Sovereignty; and those unto whom ye pray instead of Him own not so much as the white spot on a date stone. 35: 13

And for the moon We have appointed mansions till she return like an old shrivelled palm leaf. 38: 39

Lord of the two Easts, and Lord of the two Wests! 55: 17

3. THE ESTABLISHMENT OF SACRED TIME

One of the most significant and important yet badly overlooked and sadly neglected concepts of the Shariah is the concept of Sacred Time. The whole notion of the consecration, sanctity, and holiness of selected times is such an important dimension that it pervades virtually every area of a Muslim's life. Since it is such a permanent and omnipresent feature of our spiritual landscape, it practically escapes our interest.

What does Sacred Time mean? It means that the Almighty Allah has decreed a superior status to certain special moments in relation to ordinary time-periods. We are well aware that the Hilaal sets the sacred time of the month, and that the apparent rise and set of the sun and the stars provides the daily time-keeping information for the observance of the fard Salaah and certain other forms of Ibadah. As Muslims we are constantly inspired, motivated to perform certain Ibadah in specific times. The performance of the said Ibadah within meticulously prescribed time periods has always been an integral part of a Muslim's devotional routine. The performance of these forms

And he hath constrained the night and the day and the sun and the moon to be of service unto you, and the stars are made subservient by His command. Lo! herein indeed are portents for people who have sense. **Holy Quran 16: 12**

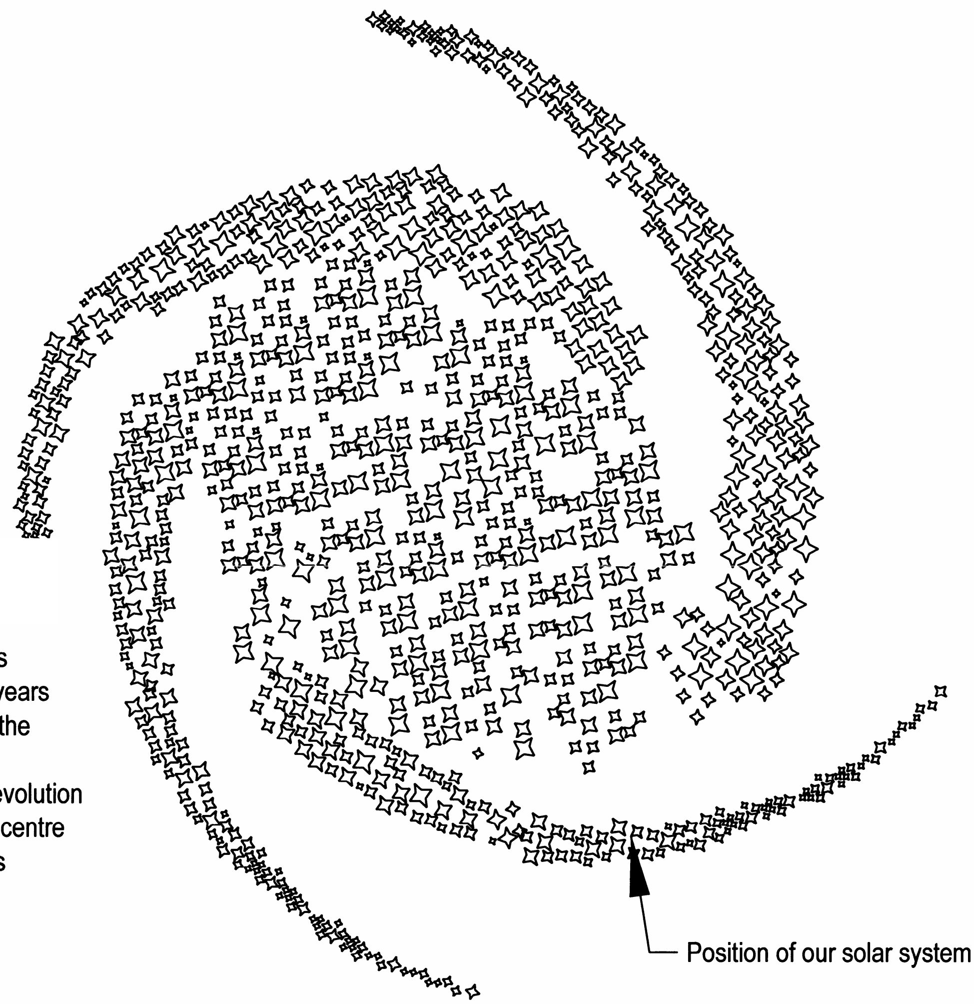
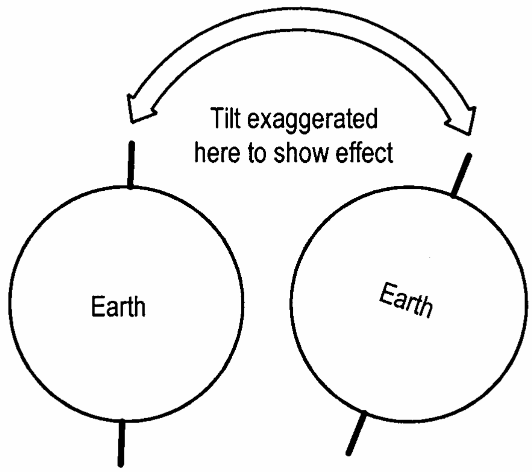
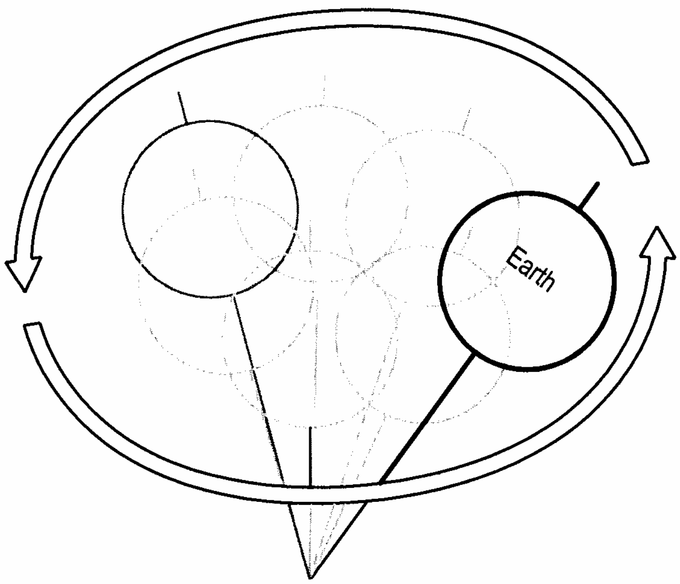


Figure 1

Our solar system is 26 thousand light years from the centre of the Milky Way galaxy. The period of its revolution around the galaxy centre is 230 million years

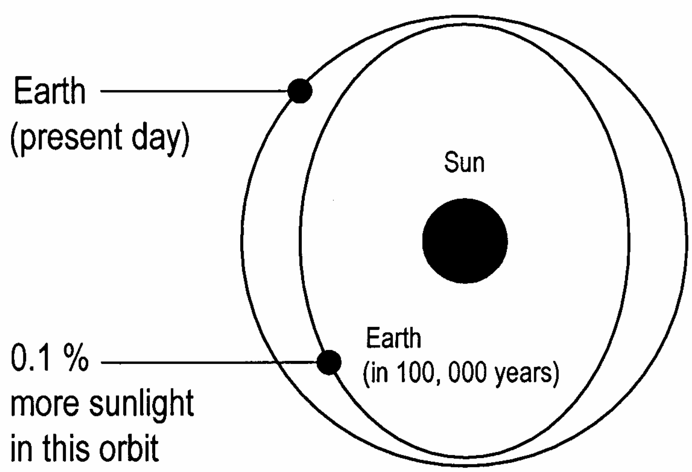
a) TILT
The tilt of Earth's axis varies from 22° to 25° over 41,000 years. The greater the tilt, the more summer sunlight falls on the poles, contributing to glacial retreat





b) WOBBLE
Earth wobbles like a toy in a cycle that lasts 23,000 years, changing the fraction of sunlight that strikes each hemisphere

c) ORBIT
The shape of Earth's path around the sun ranges from circular to more elliptical over 100, 000 years. A circular orbit means less sunlight over the course of the year.



of Ibadah consists not only in the execution of the act of prayer, but also of the execution of that act in its prescribed time slot. If an act of the aforesaid Ibadah is not enacted within its prescribed time slot it would not be regarded as being executed. If the said Ibadah is performed after its duly prescribed time it is Qada (delayed).

The Ibadah cannot under any circumstances be deliberately observed before it's due time period – this results in a flagrant disobedience to Allah's Law and can be considered in the category of a sin. Such an enactment renders that particular Ibadah as null and void and without any merit whatsoever. In Islam, the prerogative to sanctify and consecrate time belongs exclusively to the Almighty Allah. He has the sole right to invest selected time periods with superior merit and value. No human being has been given this aforementioned right. We, as Muslims, never had and will never have the right to consecrate time.

It has been Divinely Ordained that the Hilaal is the sign that ushers in each new month. The months are lunar months because the Hilaal is the marker that begins the Month. [Extract from article presented by Abdurrazak Ebrahim at the 3rd Islamic Astronomical Conference held at Amman, Jordan from Amman, Jordan from October 20 to 22, 2003].

4. OUR SOLAR SYSTEM AND IT'S POSITION WITHIN THE UNIVERSE

Our sun is only one of a very large number of stars that constitute our galaxy, the Milky Way. To be more precise there are around 100 billion stars within our galaxy and there are around 500 billion galaxies within the Universe! Our sun, along with its entire solar system, is 26 thousand light years from the centre of the galaxy. The period of its revolution around the galaxy centre is 230 million years. Figure 1 shows a rough schematic of the position of our solar system within the galaxy.

A solar day is defined to be the interval of time from the moment the sun crosses the local meridian to the next time it crosses the same meridian. Owing to the fact that the earth rotates in a diurnal cycle as well as moves forward in its orbit, the time required for one full rotation of the earth is less than a solar day by about 4 minutes. Table 1 presents information on terrestrial and other related time cycles.

The Earth's rotation about its own axis and its revolution around the sun is very involved. Over and above its rotation about its polar axis in one sidereal day and its orbital motion around the sun in a year, the tilt of Earth's axis varies from 22 to 25 over a period of around 41,000 years. The greater the tilt, the more summer sunlight falls on the poles, partly contributing to glacial retreat. Furthermore, the Earth wobbles like a spinning top in a cycle that lasts 23,000 years, changing the fraction of sunlight that falls on each hemisphere. Lastly, the Earth's path around the sun alternates between a circular to elliptical orbit with a period of 100,000 years. A circular orbit results in less sunlight over the course of the year. The above mentioned terrestrial movements have been graphically shown in Figure 2. Further information in this respect may be obtained from the Lamont Doherty Earth Observatory of Brown University, USA.

A further point of interest is that owing to Earth's tidal drag, the day-length has been slowly increasing at the rate of 21.6 microseconds per year.

5. THE SOLAR EQUATION OF TIME, DECLINATION AND SUN-PATH DIAGRAMS

The solar day defined above varies in length throughout the year due to:

a) the tilt of the earth's axis with respect to the plane of the ecliptic containing the respective centres of sun and the earth, and,
b) the angle swept out by the earth-sun vector during any given period of time, which depends upon the earth's position in its orbit (see Figure 3). Note that Table 2 presents information on the minimum and maximum Earth-Sun orbital distance along with data for other planets within our solar system.

Thus, the standard time (as recorded by clocks running at a constant speed) differs from the solar time. The difference between the standard time and solar time is defined as the equation of time, EOT.

The angle between the earth-sun vector and the equatorial plane is called the solar declination angle, DEC. As an adopted convention DEC is considered to be positive when the earth-sun vector lies northwards of the equatorial plane. Declination may also be defined as the angular position of the sun at noon (apparent solar time) with respect to the equatorial plane. For computer use, the monographs by Muneer et al (2000) and Muneer (2004) provide the highly accurate Yallop algorithm for EOT and DEC in hard- and soft-formats.

Figure 4 shows the angles relevant to the determination of sun's position and the geometry for a tilted surface.

Often people prefer to use paper-based tools such as nomograms that provide a quick and ready reference for sun's position in the sky. Towards that end, Figure 5 is provided (for Edinburgh, UK). The use of this nomogram is now demonstrated via Example 1.

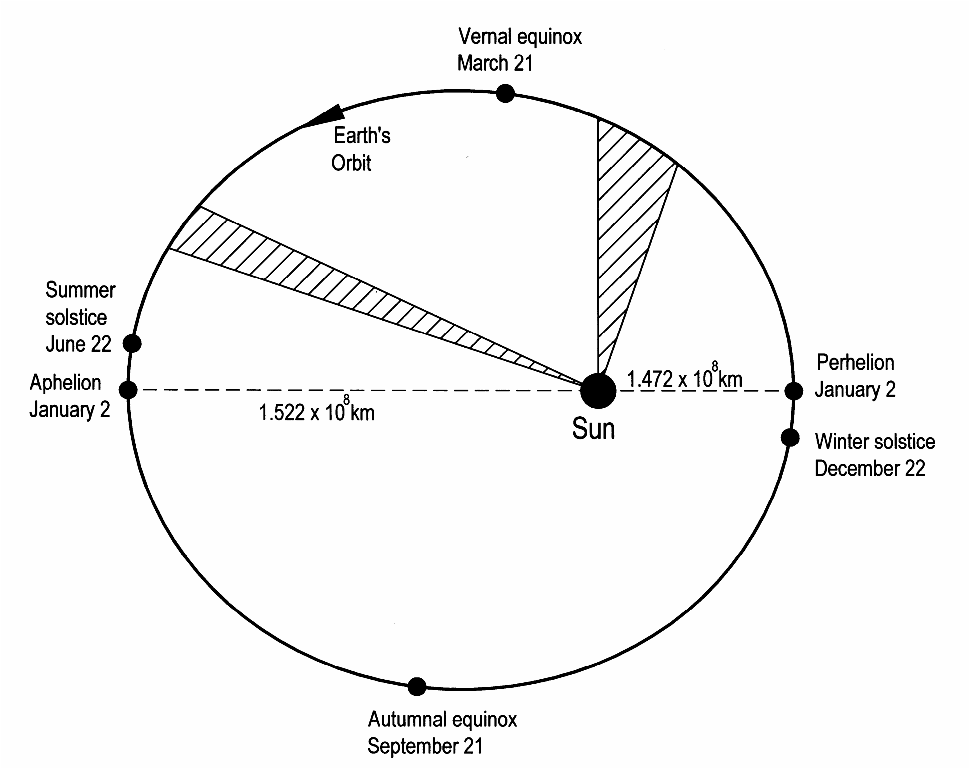


Figure 3 Earth's orbit around the sun

And He it is Who created the night and the day, and the sun and the moon. They float, each in an orbit.
Holy Quran 21: 33

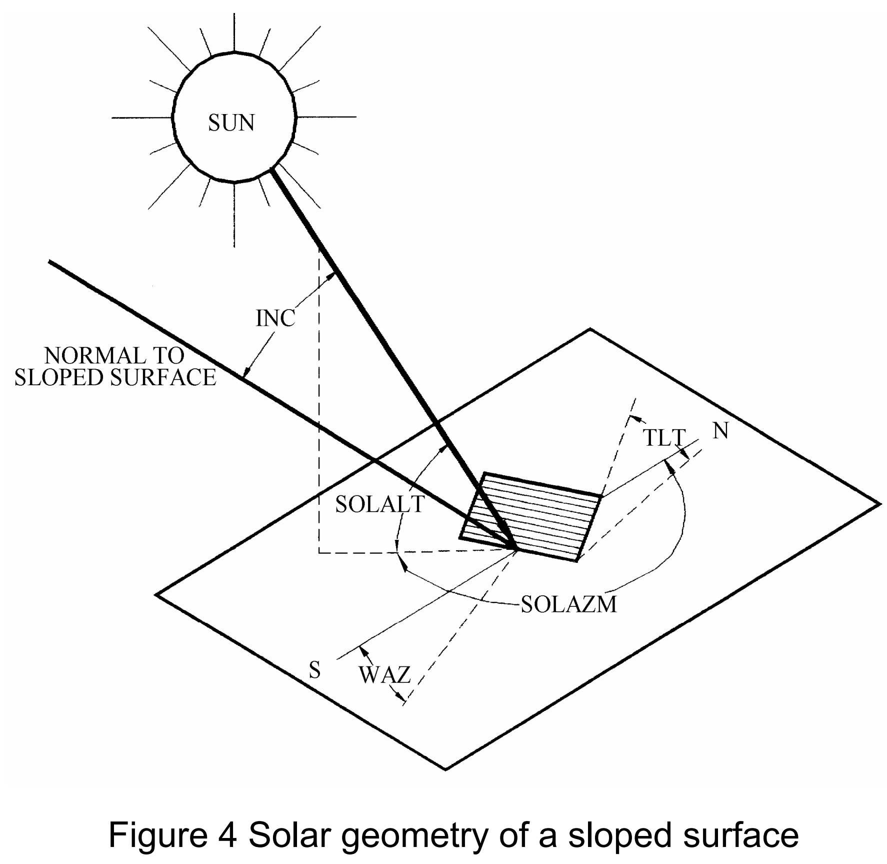


Figure 4 Solar geometry of a sloped surface

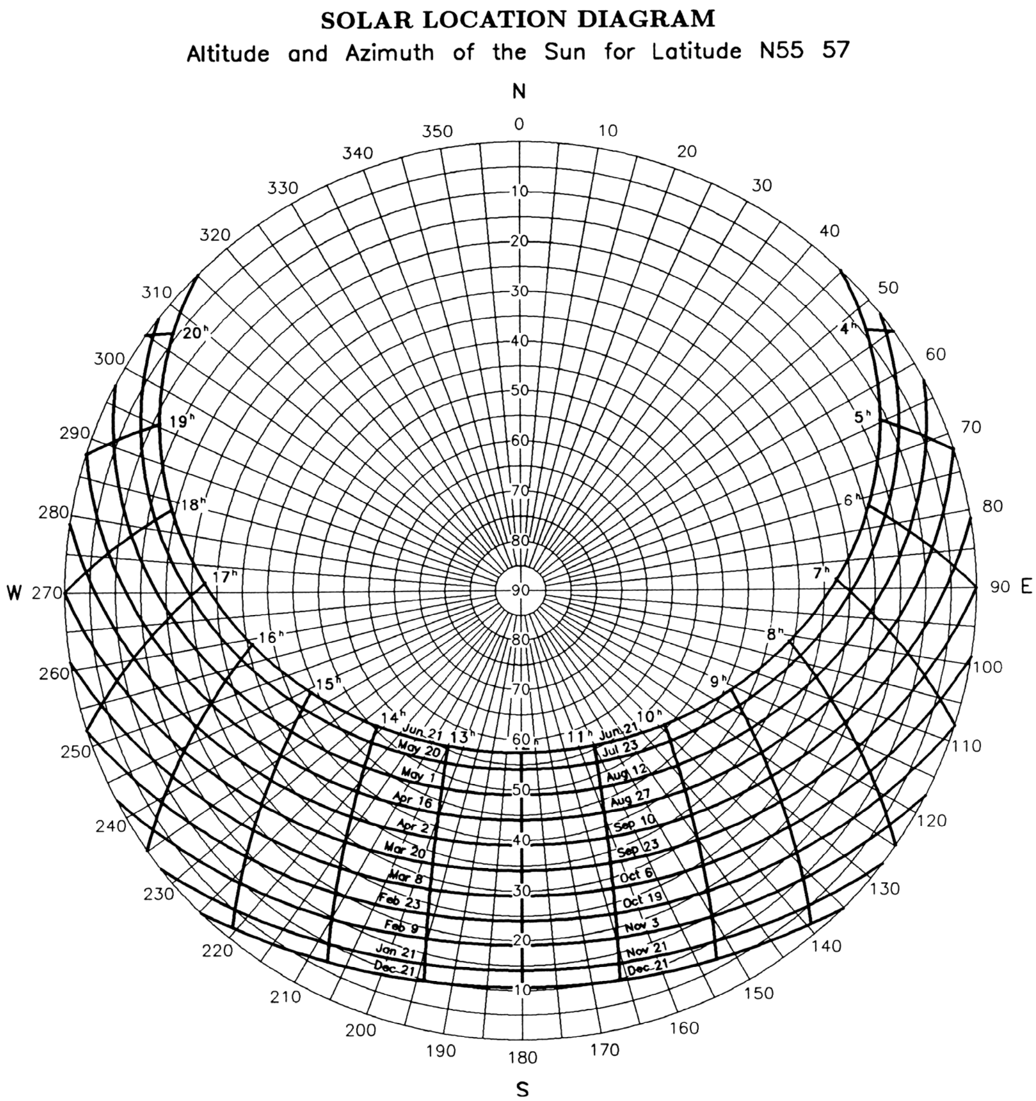


Figure 5 Sun path diagram for Edinburgh 55.95°N

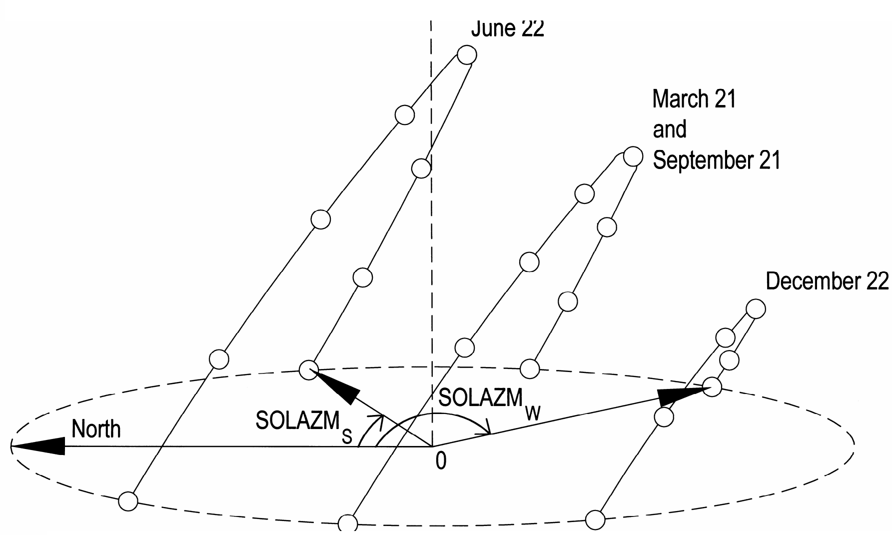


Figure 6 Trace of sun's path for northerly location

Lord of the two Easts, and Lord of the two Wests! Holy Quran 55: 17

Note that nomograms for any given location may be produced by using Prog1-6 from Muneer's book (2004) after suitable modifications have been made to execute it in a dual-nested loop, one loop for given dates and the other for time of the day.

Example 1
Using Fig. 5 which presents the sun-path diagram for Edinburgh (55.95 degree North), obtain the solar altitude and solar azimuth for May 1st at 1300 hours solar time.

A graphical solution to the above problem may easily be obtained via intersection of the curvilinear lines for May 1st and 1300 hours (13 h). The solar altitude and azimuth are respectively read off as 47.5- and 202 degrees. Note that Prog1-6.Exe gives the corresponding outputs as 47.512 5 and 201.718 3 degrees.

Figure 6 shows the sun's trajectory for a northerly location. Note the shift of solar azimuth angle for sunrise and sunset when the season changes from mid-winter mid-summer.

6. ASTRONOMICAL VERSUS ACTUAL SUNRISE AND SUNSET

Astronomers define sunrise and sunset as the moment at which the centre of the solar disk is along the horizon of the earth. It was shown above that sun's position in the sky can be determined in terms of the elevation angle (SOLALT) and the azimuth of the sun's beam from north (SOLAZM). Using Eq. (a), the sunrise / sunset instance may be computed by setting the SOLALT = 0. The sunrise / sunset instance may then be estimated by using Eq. 1.3.1 to obtain the standard time (local civil time).

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 Eq. (a) for SOLALT which refers to the instance of actual sunrise or sunset.

$$SOLALT = -0.8333 - 0.0347\, H^{0.5} \qquad (a)$$

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

7. 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. Table 3 shows the duration of twilight for various latitides.

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 SOLALT = -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 (see Fig. 7). 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 (2004).

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). Presently, Prog1-7.Exe of Muneer's book (2004) enables computation of the actual sunrise / sunset times and the above three stages of twilight. This is demonstrated via Example (2).

Example 2

For the City of Edinburgh (Lat.=55.95 N, Long.=3.2 W, Altitude=35 m.a.s.l) the sunrise / sunset times and the times for the end of civil, nautical and astronomical twilight for 1 March 1996.

Prog1-7.Exe produces the following output,

sunrise at	0702 h
sunset at	1748 h
astronomical twilight appears at	0500 h
nautical twilight appears at	0543 h
civil twilight appears at	0626 h

It is worth noting that at midsummer, between Arctic Circle and 48.5 degree North, there is a belt with no true night, i.e. the astronomical twilight extends from sunset to sunrise. This is due to the fact that the solar depression angle for June 21 for 48.5 N (and even more so for the northerly latitudes) is less than 18 degrees, the last stage of astronomical twilight. Thus, the temporal period of no true night progressively widens as one crosses to more northerly latitudes. Prog1-7.Exe has the capability to handle such cases with robustness. The reader is invited to use this particular software for any of the northern locations for dates around midsummer, e.g. estimation of the data obtained in Example 1.8.1 for London for say, June 15th.

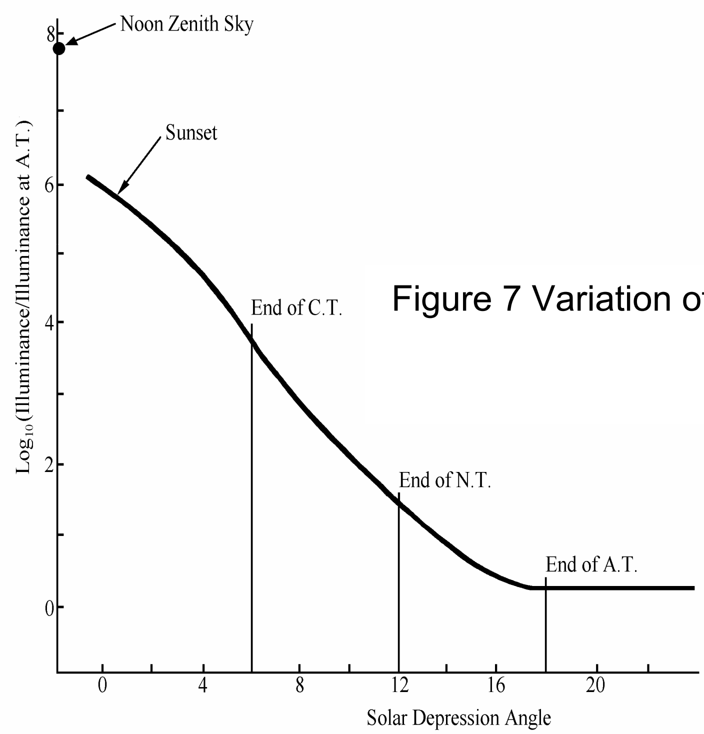


Figure 7 Variation of daylight and twilight.

Hast thou not seen how Allah causeth the night to pass into the day and causeth the day to pass into the night, and hath subdued the sun and the moon (to do their work), each running unto an appointed term; and that Allah is Informed of what ye do? **Holy Quran 31: 29**

8. COMPUTATION OF ISLAMIC PRAYER TIMES

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 book 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^{o}N and 48.5^{o}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^{o}.

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

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

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

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 sun's altitude (α) is dependent upon three quantities, the Latitude (L) of the location, the solar declination and Apparent Solar Time,

$$SIN\alpha = COS\ L * COS\ DEC * COS\ W + SIN\ L * SINDEC \quad (2)$$

$$W = 15 * (12 - AST)$$

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.

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 $\alpha = -18°$.

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,

$$\text{SIN } \alpha = \text{COS L * COS DEC + SIN L * SIN DEC} \quad (4)$$

$$\text{SIN } \alpha = \text{COS (L – DEC)}$$

$$\alpha = 90 – (\text{L –DEC}) \quad (5)$$

Assuming the height of the vertical pole to be unity, the noon shadow will then be = COT (L - 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.

Sahur and Isha times for higher latitudes

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^{o}N - e.g. Lerwick, the minimum depression angle is only 6^{o} 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^{o}. Hence for a period in summer, the midnight twilight intensity exceeds the nautical twilight limit. It may be pointed out at the nautical twilight corresponds to a solar depression of 12^{o}.

Thirdly, although the midnight solar depression for London is less than 18^{o} (astronomical twilight limit), the depression is always in excess of 15^{o} 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 jurisprudents! 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^{o}. 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 ealry 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 in 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 6^{th} 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.

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 has to be made, the first step is to find out the " normal" period and the "abnormal" period. (refer to Table 4).

During the "normal" period (the days in which sun sinks 18^o below the horizon after sun set and then appears 18^o 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.

The complete sequence of computations for obtaining prayer times are provided in Text box 2.

Note that a Visual Basic program for obtaining the salat times for the entire year is provided at author's website: http://www.jas.org.jo/muneer/

Figure 8 shows a screen dump of author's website that provides tools for computing salat times and Qibla direction.

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 5 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 is '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 5 was produced using the relationship Tan LAT = cot DEC which enables determination of the period of no sunset.


Welcome to Professor Tariq Muneer's SALAT web site
click here for Salat.pdf file
click here for salat.exe
click here for Prayer_times.exe
click here for Qibla.exe
click here for Read_this_first.txt file

Figure 8

Table 1 Time cycles and other related information

Length of tropical year as recorded in 2000 CE: 365.484 375 days
Time that the year has slowed since 1 CE: 10 s
Average decrease in terrestrial year due to decreasing angular velocity of earth: 0.5 s / century
Length of lunar year: 354.367 069 4 days
Date of enactment of Julian calendar: 46 BC
Date of enactment of Gregorian calendar: 1582 CE
Length of Gregorian year: 365.241 898 148 148 days
Length of time the Gregorian calendar had become misligned over the 414 years since enactment of Gregorian calendar: 2 hours, 59 minutes, 12 s
Year in which the Gregorian calendar will be one day ahead of the true solar year: 4909 CE
Terrestrial year measured in oscillations of atomic cesium: 290,091,200,500,000,000

Table 2 Data related to solar planetary system

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Distance (million km) from Sun									
maximum	69.7	109	152	249	816	1507	3004	4537	7375
Mean	57.9	108.2	149.6	227.9	778	1427	2870	4497	5900
minimum	45.9	107.4	147	206.7	741	1347	2735	4456	4425
Orbital period[1]	87.97d	224.7d	365.3d	687.0d	11.86y	29.46y	84.01y	164.8y	247.7y
Rotation period[2]	58.646	243.16	0.997	1.026	0.414	0.426	0.718	0.672	0.256
Orbital eccentricity	0.206	0.007	0.017	0.093	0.048	0.056	0.047	0.009	0.248
Axial inclination, degrees	2	178	23.4	24	3	26.4	98	28.8	122.5
Mass relative to Earth	0.055	0.815	1	0.11	317.9	95.2	14.6	17.2	0.002
Volume relative to Earth	0.056	0.86	1	0.15	1319	744	67	57	0.01

1 d=terrestrial days, y= terrestrial years
2 terrestrial days

Table 3 Duration of astronomical twilight

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

Table 4 Days without true night - Twilight extending from sunset to sunrise

North Latitude (Deg)	*Period of no true night*
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 5 Annual duration when the sun does not set: Arctic circle

	DEC		
Latitude	Degree	Minute	Duration
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

Text box 2 Computation procedure for 'Salat' (Islamic prayer) times

Throughout this text box reference is made to equations 1 and 2 presented in the main text above. For each of the five 'Salat' times, the first step is to use a given value for the solar altitude, or obtain it from any given condition using Eq. 2, and then use Eq. 1 to obtain the corresponding local clock time.

End of Sahur / Start of Fajr (dawn prayer) and Isha (night prayer): Use $\alpha = -18$ degree.

End of Fajr: Before sunrise

Start of Maghrib (dusk prayer): After sunset

Duhr (noon prayer): After sun's transit has taken place, i.e. following mid-noon. Use Eq. 1 and by setting AST to 1200 hours obtain the corresponding Local Standard Time (LST). A margin of say, 5 minutes may be added to the above LST for safety.

Asr (mid-afternoon prayer): A discussion on 'same-sized' (Shafi, Hanbali & Maliki formula) and 'double-sized' (Hanafi formula) shadows was provided above. Using Eq. 5 it was shown that the length of noon-shadow will be COT (L - DEC). The solar altitude corresponding to the 'same-sized' shadow would then be = ATAN [1/{1 + COT (L - DEC)}]. Likewise, the solar altitude corresponding to the 'double-sized' shadow would then be = ATAN [1/{2 + COT (L - DEC)}]. In each case, use Eqs. 2 and then 1 to respectively obtain W and LST.

9. DEFINITIONS PERTAINING TO LUNAR CRESCENT SIGHTING

9.1 Altitude and Azimuth of a Celestial Body

Figure 9 shows the altitude and azimuth of a celestial body, such as moon, at any given instance. After sunset or moonset the altitude would be negative, respectively for the Sun or Moon. The scheme of measuring the azimuth eastwards from the North is also usually adopted for determining the position of the Moon.

9.2 Difference in altitude between the solar and lunar bodies

Note that within NAO Technical Note No. 69 *ARCV* is the defined as being the geocentric difference in altitude between the centre of the Sun and the centre of the Moon for a given latitude and longitude, ignoring the effects of refraction.

9.3 Difference in azimuth between the solar and lunar bodies

As noted above the NAO Technical Note No. 69 defines *DAZ* as the difference in azimuth between the Sun and the Moon at a given latitude and longitude, the difference is in the sense azimuth of the Sun minus azimuth of the Moon.

9.4 Solar Elongation

Figure 9 explains the concept of solar elongation, which is the angular separation between Sun and Moon. On the basis of long experience the Greenwich Observatory in Cambridge, England has established that unless the Solar Elongation is greater than 10 degrees the brightness surrounding the Sun would mask the Moon from the view of the observer. However, in view of a recently published article (Records for Young Moon Sightings by B E Schaefer, I A Ahmad and L. Doggett. Quart Journal of the Royal Astronomical Observatory, Volume 34, 53-56, 1993**)** the Greenwich Observatory now accepts that under exceptionally good conditions the limiting value of the Solar Elongation may be reduced to 8.1 degrees. The Lunar crescent sighted under these conditions would be indeed very thin. Note that within NAO Technical Note No. 69 the solar elongation is given the notation of ARCL.

Note that all of the above three angles *ARCL*, *ARCV* and *DAZ*, are always expressed in degrees.

9.5 Shape of the Lunar Crescent

The astronomical calculations presented in relevant software that is readily available from numerous websites also enable the calculation of the bright-limb angle of the crescent and its bright phase. Using this information it is possible to present a computer simulation of the lunar crescent. One such simulation is presented in Figure 10. This type of information is very beneficial to the observer for then he or she knows what he or she is looking for. Note that Text box 3 & 4 respectively provide data pertaining to Moon and its black font phases.

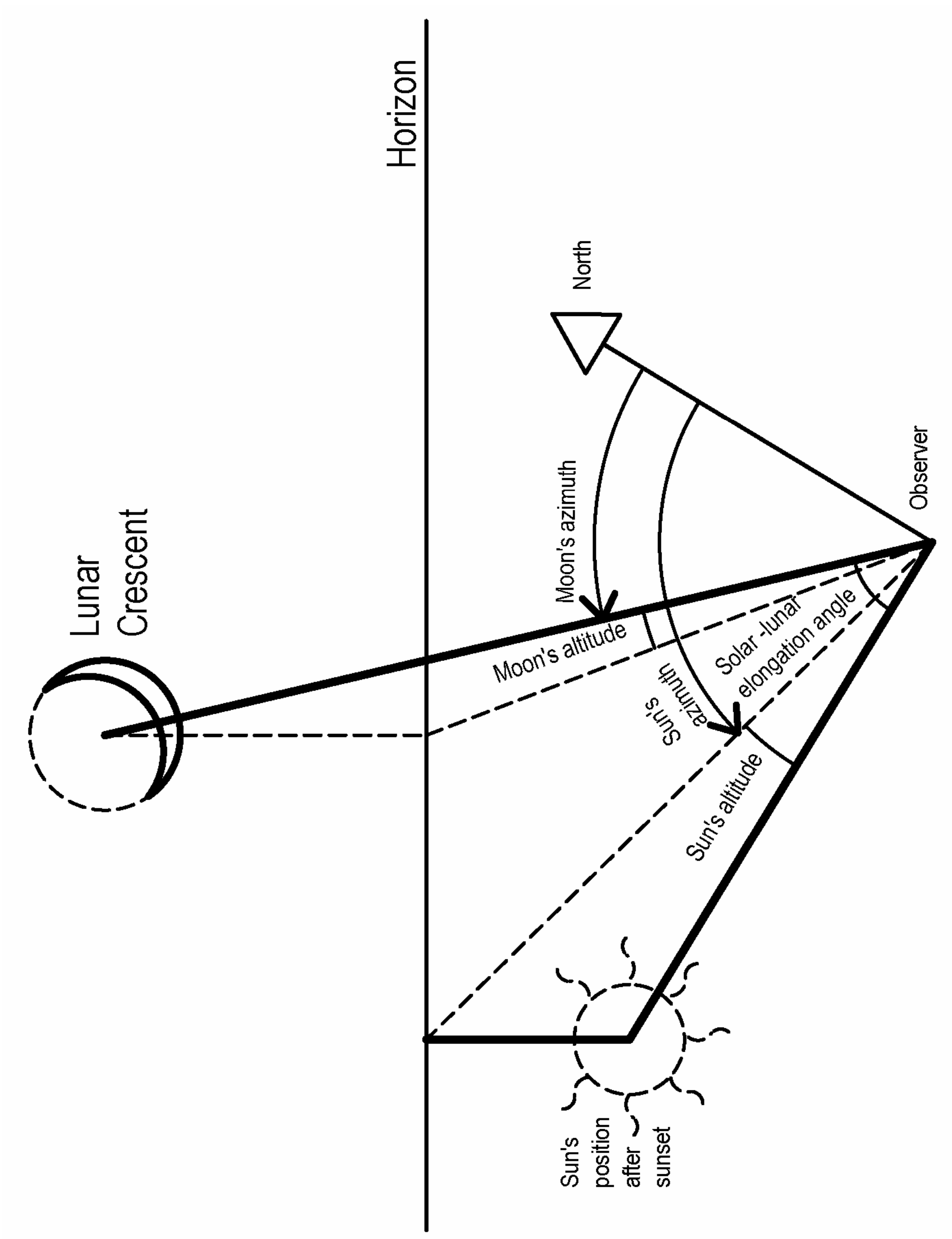


Figure 9 Solar and lunar altitude,azimuth and elongation angle

Text box 3 Basic facts about the moon

Age: 4.5 billion years old
Distance from earth: 384,467 km
Diameter: 3476 km (1/4 of the Earth's diameter)
Mass: 73,490,000 trillion tonnes
Traveling time by rocket: 13 hours
Traveling time by the speed of light: 1.52 sec
Gravity acceleration: 1.62m/s^2 (1/6 of Earth's gravity)
Rotation **period:** 27.3217 days
Mean Synodic period (new moon to new moon): 29.530588861 days
Mean orbital velocity: 1,023 km/sec

Rotation: The same side of the Moon always faces the Earth. The Moon's rotation period is synchronous with its revolution period around the Earth.
Change of distance: Because of a loss of orbital energy to gravity from the Earth, the Moon is very gradually moving away from the Earth. In the very early history of the Earth, the Moon looked about 3 times larger in apparent size in the sky, because it was closer to the Earth.

Lunar atmosphere: The Moon has almost no atmosphere, because of its weak gravity. All types of gas will escape from its surface.
Without an atmosphere, there is no wind or water erosion. The Moon's surface is about the same now as it was 3 billion years ago. The astronauts' footprints remain unchanged on the Moon's surface. The footprints should last at least 10 million years.

Temperatures: The surface temperature fluctuates from roughly +300° F during the 2-week daytime to -270 F during the 2-week night. This is because there is not enough atmosphere to keep the Moon warm at night, nor protect it from the Sun's rays in the daytime.

Lunar magnetic field: The Moon has no global magnetic field.

Sun and Moon Eclipses: An eclipse of the Sun can occur only at New Moon, while an eclipse of the Moon can occur only at Full Moon.

Tides and the moon: The moon causes many of the tides in the Earth's oceans. This is because of the gravity force between the Earth and Moon. At full Moon and new Moon, the Sun, Earth and Moon are lined up, producing the higher than normal tides.

Moon rise times: The New Moon always rises at sunrise. The first quarter Moon rises at noon. The Full Moon rises at sunset.
The last quarter Moon rises at midnight. Moonrise takes place about 50 minutes later each day than the day before.

Reference: **http://www.screensaver-download.com/moon_phases.html**

Text box 4 Names of the moon phases

New Moon

Waxing Crescent Moon

First Quarter Moon

Waxing Gibbous Moon

Full Moon

Waning Gibbous Moon

Last Quarter Moon

Waning Crescent Moon

Note: "Waxing" means growing and "waning" means shrinking.

Reference: http://www.screensaver-download.com/moon_phases.html

And for the moon We have appointed mansions till she return like an old shrivelled palm leaf. **Holy Quran 38: 39**

9.6 International Lunar Date Line (ILDL)

The concept of ILDL was first introduced by the Malaysian Astronomer M Ilyas in the year 1978. The concept is based on the earliest possible sighting for the Globe. The ILDL is the locus of tile geographical longitudes just meeting the minimum visibility condition at local sunset.

The minimum visibility condition set by the Greenwich Observatory is shall be discussed in the following section. The 'best' sighting time for the crescent is recommended as the time when the Sun has sunk 5 degrees below the horizon.

9.7 Parametric range of conditions for lunar crescent visibility

Using a calibration data base of 295 observations of the first visibility of the crescent moon taken over a period of 138 years (1869-1996) and covering most of the latitude range of up to 50 degrees, Yallop has put forward the following range of conditions for lunar crescent visibility:

$q > +0{\cdot}216$	Easily visible (ARCL ≥ 12°)
$+0{\cdot}216 \geq q > -0{\cdot}014$	Visible under perfect conditions
$-0{\cdot}014 \geq q > -0{\cdot}160$	May need optical aid to find crescent
$-0{\cdot}160 \geq q > -0{\cdot}232$	Will need optical aid to find crescent
$-0{\cdot}232 \geq q > -0{\cdot}293$	Not visible with a telescope ARCL ≤ 8·5°
$-0{\cdot}293 \geq q$	Not visible, below Danjon limit, ARCL ≤ 8°

Note that the 'q' parameter given above is determined from the following suite of equations, primarily based on the Indian method:

$$q = (\mathrm{ARCV} - (11{\cdot}8371 - 6{\cdot}3226\, W' + 0{\cdot}7319\, W'^{2} - 0{\cdot}1018\, W'^{3}))\,/\,10$$

where W' is the topocentric width of the crescent, and q is scaled to lie iin the range –1 to +1. W' is expressed as a function of the semi-diameter of the moon (SD), the geocentric altitude (h) and parallax (π) of the moon, and ARCL.

$$SD = 0{\cdot}27245\pi$$
$$SD' = SD\,(1 + \sin h \sin \pi)$$
$$W' = SD'\,(1 - \cos \mathrm{ARCL})$$

9.10 Analysis

There are three stages leading to the event of moonsighting. These stages are:

1. Birth of the new moon (Conjunction). These data are widely published and are available in almanacs, newspapers, calendars and diaries.

2. For people who do not have a rigorous exposure to knowledge of astronomy the approximate conditions for moonsighting may be taken as: (a) moonset at least 35 - 40 minutes after sunset, (b) age of moon to exceed 16 hours at the local sunset and, (c) the Sun-Earth-Moon angle (solar elongation or ARCL) usually to be in excess of 10 degrees but under very exceptional cases to be at least 8.1 degrees.

3. For those who would like to dwell in a more rigorous understanding of this subject, the NAO Technical Note No. 69 issued by the HM Nautical Almanac Office (Royal Greenwich Observatory), Cambridge, UK provides the relevant information. An extract from that reference, developed by Yallop, is now provided below. In this procedure a single parameter method for predicting first sighting of the new crescent moon, based on the Indian method is presented. The procedure was calibrated by applying a standard set of 295 first sightings of the new crescent moon that cover the period 1859 to 1996. The method is particularly suited for latitudes between 55 degree North and 55 degree South latitudes.

The following visibility 'types' for the new crescent moon can be predicted (a) easily visible to the unaided eye; (b) visible under perfect atmospheric conditions; (c) may need optical aid to find the thin crescent moon before it can be seen with the unaided eye; (d) can only be seen with binoculars or a telescope; (e) below the normal limit for detection with a telescope; and (f) not visible.

For abbreviated analysis, the basic criterion for the visibility of the crescent moon may easily be determined by evaluating the following condition, which if it is found to be true indicates the possibility of sighting:

$$ARCV > 10{\cdot}3743 - 0{\cdot}0137\,|DAZ| - 0{\cdot}0097\,DAZ^2$$

The above mathematical relationship may alternatively be expressed by means of the following table. Note that the function of DAZ, f(DAZ) in the following table is the RHS of the above mathematical relationship.

DAZ	0°	5°	10°	15°	20°
f(*ARCV*)	10·4	10·0	9·3	8·0	6·2

Thus, using the above table we may say that the possibility of lunar visibility with the naked eye exists if say, the DAZ was 10 degrees and the ARCV was 9.4 degrees.

For more precise computations for visibility, however, one may refer to the procedure laid out in Section 2.7.

4. Appropriate terrestrial and atmospheric conditions for viewing - e.g. flat terrain (ground or at sea level) and clear sky. The solar and lunar dynamics may be precisely estimated using high accuracy equations available from numerous sources. One such source is the book on 'Astronomy with your personal computer' by P Duffet-Smith, Cambridge University Press (1990).

As a rule of thumb the 'best' time for visibility has been recommended to be the instance when the sun has sunk 5 degrees below the horizon. Yallop has however further improved this computation and has proposed the following criterion:

Given that T_s is the time of sunset and T_m the moonset time, the best time T_b shall be,

$$T_b = (5\ T_s + 4\ T_m)/\ 9$$

10. WEB BASED RESOURCES FOR PROBABLE MOONSIGHTING

During the last two decades there has been an explosion in activity related to moonsighting. Although the participants of this activity are spread around the globe, a genuine impetus within the Muslim world has come from the Jordanian Astronomical Observatory. As such their web site www.jas.org.jo deserves a special mention. Although the web site contains a considerable amount of information on very many issues related to astronomy and in particular moonsighting, the section on software shall be the focus of this section. Material is available from the software section, i.e. http://www.jas.org.jo/software/index.html#1

Two software programs are worthy of discussion:

10.1 Accurate Times

Written by Mohammad Odeh, a member of the Jordanian Astronomical Society (JAS), the 'Accurate Times' software calculates the Islamic prayer times, the Qiblah direction and the Hejric-Gregorian date conversion. One of its options is to hear the call for prayer, triggered on the PC at the appropriate time. The program runs under MS-Windows (95/98/2000/NT). The program also uses the above-mentioned NAO Technical Note 69 for providing information on moon's earliest possible visibility and the lunar position in the sky at that instance.

Figure 11 provides a screen-dump of the opening page for the 'Accurate Times' software.

10.2 Moon Calculator

This software has been prepared by Dr. Monzur Ahmed of Sutton Coldfield, Birmingham. A zipped version of this software is available from the above-mentioned website.

The Moon Calculator provides information relating to the position, age, phase, orientation, appearance and visibility of the moon for any given date, time and location on earth. It also provides the Julian Day Number, Magnetic Declination, time and direction of moonrise and moonset, interval between sunset and moonset, interval between sunrise and moonrise, date/time of astronomical new moon (conjunction), full moon, apogee and perigee and predicts the likelihood of visualising the young moon from a particular location. Data pertaining to solar and lunar eclipses in any year are also shown. Hijri calendar data including location dependent Hijri date conversion using predicted crescent visibility are also provided.

The program can scan the globe at the start of any lunar month to find the location, date/time and circumstances of earliest crescent sighting using a variety of ancient and modern moon sighting criteria. The program is able to draw world maps (flat and spherical projections) showing areas of the globe where the young moon is likely to be seen. Graphical displays showing the position of the moon on a star chart and the position of the moon in a simulated local sky (horizon view or traditional circular sky-chart view) can be produced and printed out. A close-up of the near side of the moon (showing orientation of the moon's limbs and position of the lunar craters), correct for a given observation site, is also provided. A validation of this software is provided in Figure 10.

Note that the above software can directly be downloaded from this website:
http://www.ummah.org.uk/ildl/mooncalc.html

Example 3

Use Accurate Times and Moon Calculator programs to invesitigate the new moon visibility for the start of Ramadan 1425 Hijri for London, UK.

Using any of the above two programs it is an easy matter to obtain the date for earliest visibility. In this case the answer obtained is 15 October 2004 and the best time for the visibility is indicated as 1719 hours. The following data related to the lunar crescent corresponding to the latterly mentioned time is provided:
Moon age = 38.8 hours
Moon altitude = 3 degrees
Moon azimuth = 237 degrees
Sun-Moon elongation = 21 degrees

Image of moon captured through the lens of a JVC DV-X4digital video camera (left). Photo taken by Professor Tariq Muneer in Edinburgh (Latitude = 55.95 North, Longitude = 3.2 West) at 1900 hours on 10 January 2000 (3 Shawwal 1420 AH). Computer simulation of moon for the above time generated by Moon calculator program version 5.2. This software is available from http://www.ummah.org.uk/ildl/mooncalc.html.

The remarkable similarity between the computer and video image thus provides a validation of the above software. Relevant data: Moon age = 94 hours, phase = 0.14, bright limb angle = 252 degrees.

Figure 10 Validation of Moon calculator program

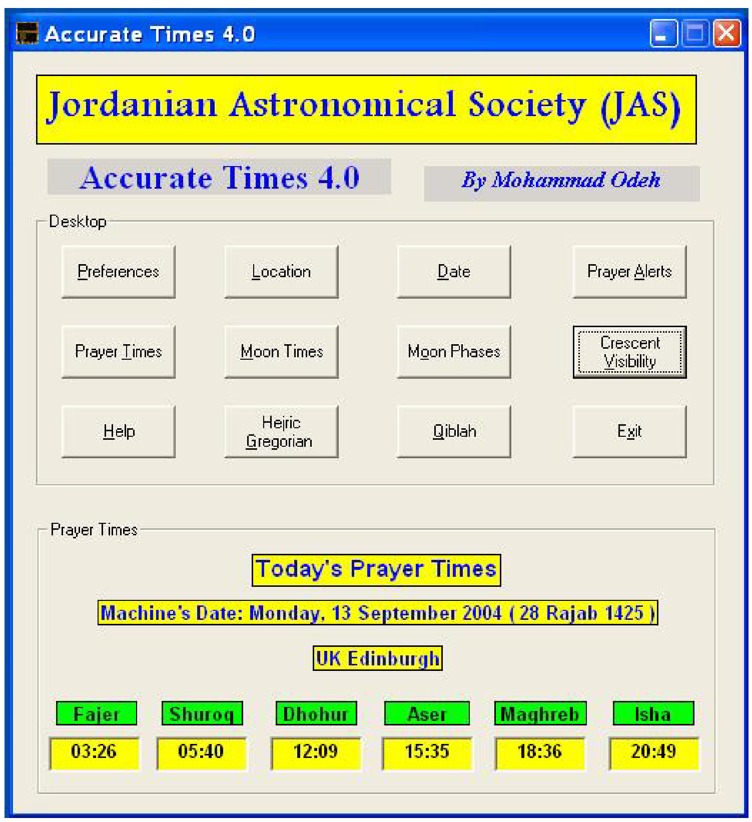


Figure 11 Screen Dump from 'Acurate Times' software. Note that this software is available from the website: http://www.jas.org.jo/software/index.html#1

11. MOONSIGHTING REPORTS

Islam has provided a very direct and easy means for determining the start/end of any given month, i.e. with the visibility of the young crescent moon. However, as we all know due to dubious reports of moonsighting a great deal of confusion is generated. One way to avoid this confusion and to harmonise the lunar calendar that is based on the principles of Shariah is to obtain detailed reports (including textual and photographic information) regarding moonsighting. In this respect the above-mentioned Jordanian Astronomical Society has set up a worthy system of receiving such reports which are then posted on their web site. The following is a good example of one such report. Note that the extremely thin crescent is over 22 hours old. How can then one expect to accept claims of moonsighting that show the moon's age to be of a single digit or less?

Reporter: J Stamm. New Moon Crescent Observability on October 14, 2004
Time from geocentric new at sunset = 22 hours 04 minutes at Tucson, Arizona, USA.
Gates Pass: Long. = 111.10 W, Lat. = 32.22 N, Elevation = 963 meters, Temp. = 79 F, RH = 13%. Crescent first observed through 8" SC telescope: Time = 6:08 p.m. (MST) 01:08 (UT). Altitude=1.9 degrees, Azimuth=252.6 degrees, Sun-Moon Elongation = 11.5 degrees, Percent of surface that was lit = 1.0 percent.

12. MOONSIGHTING IN A RELIGIOUS PERSPECTIVE

A large number of commands that belong to the Islamic Sharia law are based on the date of the Islamic month and/or the day of the week. Ever since Allah Subhana Wa Tala created the Earth, all divine religions have based their annual calendar on a 12-month cycle and this is the divine command, e.g. ‘The number of months in the sight of Allah is twelve (in a year) – so ordained by Him the day He created the heavens and the earth …’ (Holy Quran 9:36). The Islamic calendar has a lunar base and the number of days within the month varies between 29 and 30.

The Islamic months are:
1. Muharram 2. Safar 3. Rabi-ul-Awal 4. Rabi-ul-Akhir
5. Jamadi-ul-Awal 6. Jamadi-ul-Akhir 7. Rajab 8. Shaban
9. Ramadan 10. Shawwal 11. Dhi-Qaad 12. Dhul-Hajj

Currently, the lunar calendars that are regularly published by Islamic governments are based on astronomical calculations. In this respect there seems to be a wide variation of practice. These are enumerated below:

A) Birth of new moon occurring before midnight GMT indicates start of month from the following day. This formula was the basis of the older, 32-year Saudi official calendar published by the King Abdul Aziz City for Science & Technology, Riyadh.
B) Following the birth of new moon, moonset to occur after sunset. This seems to be the formula for the current Saudi official calendar. The Egyptian calendar is also based on this formula.
C) Determination of the number of days in a month depending upon whether the month number is odd (30-day month) or even (29-day month). In yet other systems this order may be reversed, i.e. odd numbered months get 29 days and so on.
D) Declaration of the start of lunar month following ‘probable moonsighting (IMKAN-E-RUYAH)’. The probable moonsighting may be determined by incorporating the results obtained from the use of the above-mentioned software. A large body of Muslim scientists, including those affiliated with the Jordanian Astronomical Society (see Figure 11) are proposing the adoption of this system.
E) Actual moonsighting. This system is prevalent within Morocco and the Indian subcontinent, i.e. Pakistan, India and Bangladesh.

Islamic month and astronomical calculations

The determination of the start of any given lunar month can be ascertained in light of the Hadith of our Prophet (Salle Allah Wa Alaihi Wa Sallam): Start fasting and celebrate ‘Eid’ after sighting the moon and if the moon is not sighted then complete the 30 days of Shaban and Ramadan. It is for certain that the sighting of the new moon will take place after the conjunction (birth of new moon) event. The astronomical calculations have developed to the extent that the birth of the new moon may be computed to an accuracy of within a second. For an assessment of the possibility of moonsighting it has to be borne in mind that the following factors are of relevance:

i- The terrestrial location for the earliest moonsighting changes every month.

ii- All locations that are west of the above location will have the chance to sight the moon, provided the horizon is not overcast that evening. Locations that are east of the earliest sightable locality will 'see' the moon the following day.

iii- For the sighting of the new moon, the following conditions are to be met:

a- Following the conjunction event the new moon is above the horizon.

b- The altitude is high enough for sighting to take place.

c- The solar elongation angle (ARCL) is above the appropriate limit.

d- The moon stays above the horizon long enough after sunset so that the background sky attains the required darkness.

e- Clouds, dust or aerosols do not cover the horizon.

f- The observer has no defects in his sight.

If reports of alleged moonsighting are received that are in contradiction to the conditions laid out the list above (iii – a through to d) then that report would be questionable. This has been the accepted verdict and resolution of numerous international moonsighting conferences. In this respect the author (Y I Qasmi) has attended a dozen conferences. It was unanimously agreed in those conferences that those reports of moonsighting that are in contradiction of the earliest conditions for sighting are either false or unreliable.

The final question that arises at this point is that given the conditions for moonsighting have been met, but the horizon is obscured with clouds, would it be acceptable to declare the start of the Islamic month? In this respect the author of this note agrees with the majority of the scholars that such a declaration would have to wait for the month to complete its course of 30 days. However, a number of Muslim scholars have given their verdict that it is acceptable to initiate the lunar month based on the dictum of 'probable moonsighting - IMKAN-E-RUYAH' (see item 'D' above). The names of those scholars are given below (all dates in Christian Era, CE):

Matraf bin-Abdullah bin-Shaqeer (Died 706), Muhammad bin-Muqatil Al-Raazi (805), Ibn-Qatiba al-Deenwari (889), Abu-Al-Abbas Ahmed bin-Omar bin-Sareej Al-Sahfie (918), Faqaal, Qazi Abdul-Jabbar (1024), Ibn-Daqeeq Al-Eid (1302), Taqi-Al-Din Subki (1355), Qazi Abu-Tayyab and Shams Al-Din Al-Ramli (1595), Muhammad Taher bin-Ashoor (1867), Jamal Al-Din Qasmi (1914), Muhammad Bakheet Al-Mutee and Muhammad Rasheed Raza Masri (1935), Jawheri Tantawi Masri (1940), Mustafa Muraghi (1945), Kamal Meeras (1957), Muhammad Ali Al-Salees (and Ahmed Muhammad Shaker (1958) and scholars from the current period such as Yusuf Qardawi, Shaikh Mukhtar Salami Tunis, Mustafa Zarqa (RA) and Mustafa Kamal Tarzi Tunis (RA).

13. WHY A PURELY LUNAR CALENDAR?

The well-known scholar of Islam, the late Professor Muhammad Hamidullah has presented the following arguments in his well known book, 'An Introduction to Islam, MWH London Publishers, 1979'. In pre-Islamic Arabia intercalation of months was known and practised. The Holy Prophet abolished it when he received Quranic revelation (9:37) condemning the intercalation. There is a good reason for having a rotation of the months round the solar calendar, so that one experiences the food and drink privations in all seasons – neither always hardship nor always easy going lot.

14. ALGORITHM FOR QIBLA DIRECTION

It has been mentioned above that with the rapid spread of Islam the determination of prayer times and the direction of Makkah (Qibla) were required for new locations that came under the control and care of Muslims. Early Muslim astronomers were therefore engaged in the development of spherical trigonometry. A result of that work, and in continuation of the earlier work of the Greek mathematicians produced the algorithms that are used in great circle navigation. The algorithm given below provides the distance and heading (for shortest flight path) from any given source to a given destination.

If we denote the geographical latitudes of the source and destination, respectively as, LatS and LatD and the longitudes as LongS and LongD, then the distance between the locations is obtainable from the following suite of equations,

$$\text{Dterm} = [\sin(\text{LatS}).\sin(\text{LatD})+\cos(\text{LatS}).\cos(\text{LatD}).\cos(\text{LongD}-\text{LongS})] \quad (6)$$

$$\text{Distance (nautical miles)} = 60 * (180/\pi)*\cos^{-1}(\text{Dterm}) \quad (7)$$

$$\text{Distance (km)} = \text{Distance (miles)} * 1.852 \quad (8)$$

$$\text{Hterm1} = (180/\pi)*\cos^{-1}[\{\sin(\text{LatD})- \sin(\text{LatS})\}/\{\cos(\text{LatS}).(1-\text{Dterm}^2)^{0.5}\}] \quad (9)$$

$$\text{Hterm2} = \sin[\text{LongS}-\text{LongD}] \quad (10)$$

$$\text{Heading} = \text{Hterm1 if Hterm2} > 0\text{, else} = 360-\text{Hterm1} \quad (11)$$

Equation 7 provides the distance between the source and destination in nautical miles. The nautical mile is an international unit used in sea and air navigation, being 1,852 metres. Incidentally the older, British nautical mile = 6080 ft and hence this equals 1,853 metres. The nautical mile is defined as the distance subtended at the earth's equatorial plane by one minute of latitude. A speed of one nautical mile per hour is defined as one knot, an international unit for designating sea, air and wind speeds.

Note that 'Heading' is the clockwise direction from the true north that one would fly from source to destination. In the present case source would be the location for which Qibla direction is sought and destination is Makkah. The latitude and longitude of Makkah are respectively, 21^o 25' 22'' North and 39^o 49' 31'' East. More exact coordinates for Ka'bah are 21^o 25' 24'' North and 39^o 49' 24'' East, as reported by the Army Corps of Engineers, Pakistan.

Khalid Shaukat has undertaken some work with respect to the determination of Qibla Direction for the North American sites. The material available on his website, http://moonsighting.com/qibla.html, provides an interesting discussion on the controversy of Qibla for North American locations. One group of people favours the direction of South-East while another group favours North-East. It may easily be shown via application of the above great circle navigation principle that those who favour South-East are mislead by looking at the flat map with an argument that Makkah is south and East of North America. It must be borne in mind that the earth is not a flat plane. It is more like a sphere. The shortest route from any North American location to Makkah will go over the north pole. So, the Qibla from these locations will be towards North.

Another method that does not rely on the use of magnetic compass, uses the sun position. It must be noted that twice a year the sun comes overhead above Ka'bah. Those two dates and times are: **May 28 at 9:18** and **July 16 at 9:27**, all times being in GMT. This fact may be used to set the correct Qibla direction in places far from Makkah, as it has been used by Muslims for the past centuries. When one observes the sun at his or her location at these GMT times, one will be facing the Ka'bah. For example, for someone who is residing in Islamabad, Pakistan (local time = GMT+5 hours), the local time to observe the sun would be 2:18pm on May 28, and 2:27pm on July 16. If for some reason one cannot see the sun on the above mentioned two dates, then Qibla may still be located from the sun when it comes overhead at a point diametrically opposite of Makkah (on the other side of the sphere) on **November 28 at 21:09** and **January 16 at 21:29 GMT.** In this case one would face towards the shadow from the sun at these times to face Ka'bah.

A Visual Basic program for the computational scheme based on the principle of great circle navigation is provided at author's website: http://www.jas.org.jo/muneer/

15. CONCLUSION

One of the most eloquent verses of the Holy Quran pertaining to the laws of motion of the heavenly bodies states thus, ‘The sun and moon follow courses (exactly) computed (55:5)’. Furthermore, Allah Subhana Wa Taala, through His immense Mercy provided wisdom and education to Man so that he was able to comprehend the above laws of motion, i.e. ‘For Allah hath sent down to thee the Book and Wisdom and taught what thou Knewest not before: And great is the Grace of Allah unto thee (Holy Quran 4:113)’ and also, ‘Who teacheth by the pen, Teacheth man that which he knew not.’ (Holy Quran 96:4-5)’. All heavenly bodies traverse in their predetermined paths, in perfect obedience to Divine laws, i.e. ‘It is not permitted to the Sun to catch up the Moon, nor can the Night outstrip the Day: Each (just) swims along in (its own) orbit (according to the law) (Holy Quran 36:40)’.

During the past century, the computations related to solar and lunar movements and of the motion of planets within the solar system have achieved very high accuracy gains. It may be of interest to note that up to early seventeenth century the equation of time, then known as Equation Naturales, could be computed with an accuracy of half a minute. In 1675 Flamsteed Street, the first Astronomer Royal in England produced a technique to reduce the error in obtaining EOT to within 6 seconds. Today there are equations available that have an accuracy of 3 seconds over a range of 60 centuries. In this respect the reader is referred to the work of Hughes, D.W., Yallop, B.D. and Hohenkerk, C.Y., ‘The equation of time’. Mon. Not. R. Astr. Soc. 238, 1529 (1989).

In a manner similar to the locality related variation of rising and setting of the sun, the movement of the moon is not dissimilar and hence conditions for the earliest sighting of the moon vary from one place to another. Furthermore, there is clear guidance provided in Hadith regarding the latter phenomenon and in the language of *shariah* it is referred as *Ikhtalaf-e-Matale*. Hence, it must be borne in mind that the moonsighting report for the Middle-East may or may not be applicable to the United Kingdom. Each geographical zone of the planet earth will have its own unique set of conditions for probable moonsighting (IMKAN-E-RUYAH). It was shown Section 5 of this monograph that there is room to adopt the solution of probable moonsighting. The probable moonsighting may be determined by incorporating the results obtained from the use of the above-mentioned software. A large body of Muslim scientists, including those affiliated with the Jordanian Astronomical Society (see Figure 11) are proposing the adoption of this system.

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