EARLY ASTRONOMY - THE CELESTIAL CYCLES

It is hard for modern Man, surrounded by the technical apparatus he has used to dominate his environment, to appreciate why his predecessors thousands of years ago observed the skies as fully as they did. In a society where food comes from a store, heat and light from the flick of a switch, the time and date from radio and TV, we can regard the sky over our heads as little more than an ornament or a source of academic puzzles for a few astronomers. We can afford to forget the essentially practical interest in astronomy developed by earlier, less technological societies of man.

But history shows that the sciences of medicine and astronomy emerged as organised disciplines thousands of years before systematic physics or chemistry, on which so much of today's ubiquitous technology is based. While the concerns early men had with medicine are still with us, those which fostered the early growth of astronomy are less obvious to us now because our technology and level of civil organisation insulate us from them. Astronomy has its roots in time-keeping, calendar-keeping, regulation of agriculture, and navigation.

In this chapter we shall see that early Man made much use of what he saw in the skies unaided by telescopes. The very utility of what he found set him on a course of systematic observation and interpretation of the cosmos which has proceeded, with major interruptions, for some five thousand years and which is far from complete today. In beginning our account of the physical world with a study of early astronomy, we shall see the dawn of the scientific method while beginning our own familiarisation with celestial phenomena.

1. The daily cycle of celestial bodies

The unending succession of night and day is the most obvious of all sky phenomena, as its rhythm profoundly influences all life on Earth. Even the most casual observation of the sky shows that Sun, Moon and stars alike apparently share a common daily revolution over our heads, from generally eastwards directions towards generally westwards directions as time passes. Early Man wondered if the <u>same</u> Sun and Moon come into the sky each day; the Moon shows a different aspect between crescent and full face every time it rises, and the Sun does not rise from the same point on the horizon every day nor set at the same point every night. These phenomena occur because both Sun and Moon combine other, longer-term motions with their daily cycle. The daily cycle is seen most clearly, unmixed with others, in the apparent motions of the stars.

Stand outdoors on a clear night facing North. Somewhere in the sky before you, exactly where depending on time of day and year, you will see the famous grouping (constellation) of bright stars called the "Big Dipper" (or the "Plough"). A line drawn away from the two bright stars on the steep side of the "Dipper" (the blade of the "Plough") as in Figure 1 passes close to the bright star Polaris, which is a little less than one degree away from the point in the Northern sky about which all celestial bodies presently appear to turn once each day. If the glare of sunlight scattered by the Earth's atmosphere did not obliterate the fainter light of the stars while the Sun is above our horizon, we should see the Big Dipper stars in each of the configurations shown in Figure 2 throughout 24 hours. In fact the full 24-hour cycle can be seen only in the Northern hemisphere of Earth from latitudes North of the Arctic Circle during winter, when the Sun does not rise above the horizon. Careful observation over a few night-time hours will however show part of this cycle from any Northern latitude at any time of year. Figure 3 shows a time-exposure photograph of a few degrees of sky around Polaris. The apparent motions of the stars in the sky over the camera traced curved trails on the photographic plate, each part of a circle centred on the same point in the sky - the celestial North Pole.

For any one Northern observer, a small area of the sky is close enough to the celestial North Pole that the daily circles of all stars in it lie entirely above the observer's horizon. The stars within this so-called "circumpolar" area never rise or set; all are visible to that observer at any time during the hours of darkness between sunset and sunrise. If you were to stand at the Earth's North Pole, the circumpolar area of your sky would fill the whole visible hemisphere, as the celestial North Pole would be vertically over your head (Figure 4). In more commonplace Northern latitudes, only a fraction of the sky is seen to be circumpolar, this fraction diminishing as the Earth's Equator is approached. The "Big Dipper" is so frequently singled out as a 'finder' constellation for Polaris (and hence for the Northerly

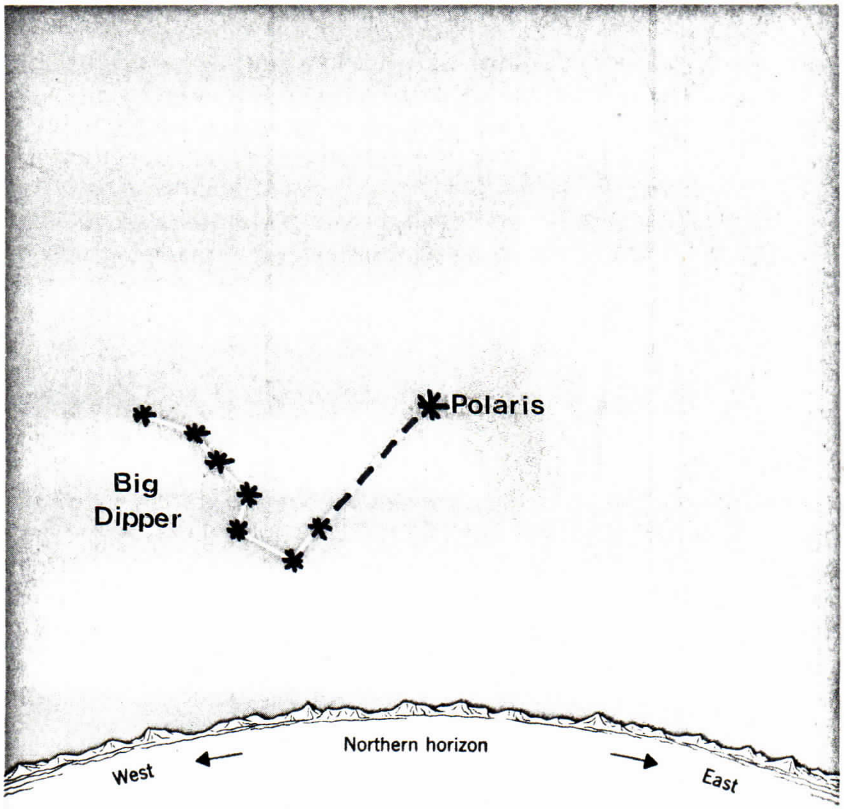

Polaris
Big
Dipper
Northern horizon
West
East

Fig 1

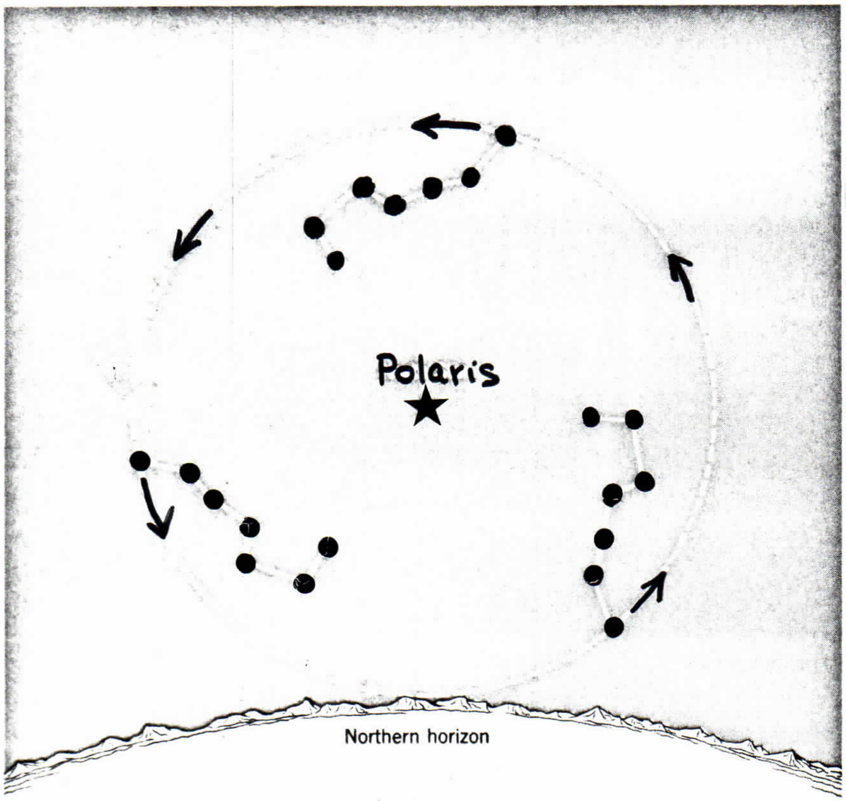

Polaris
Northern horizon

Fig. 2

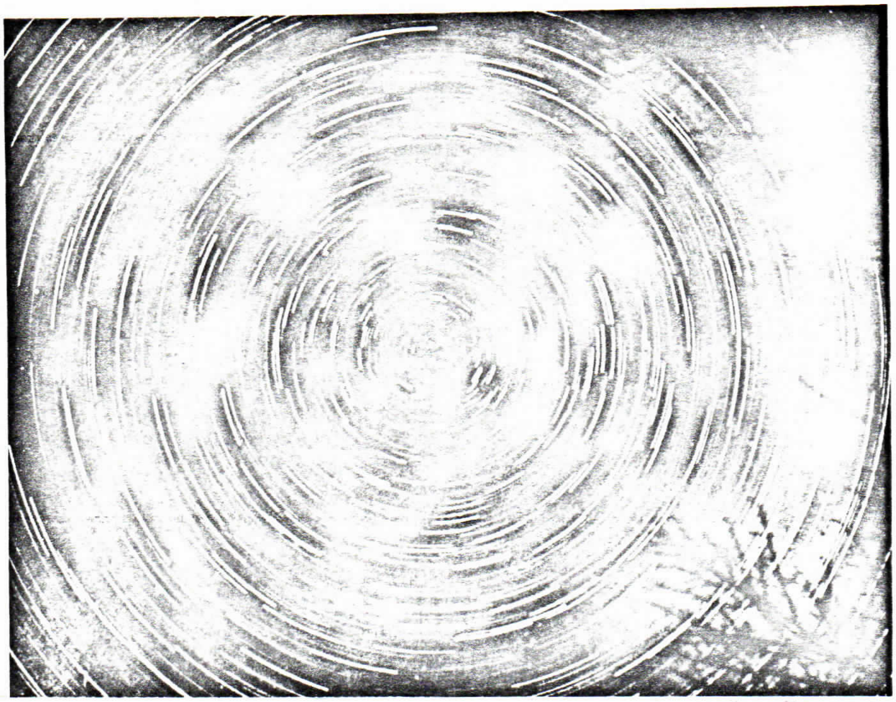


Fig. 3

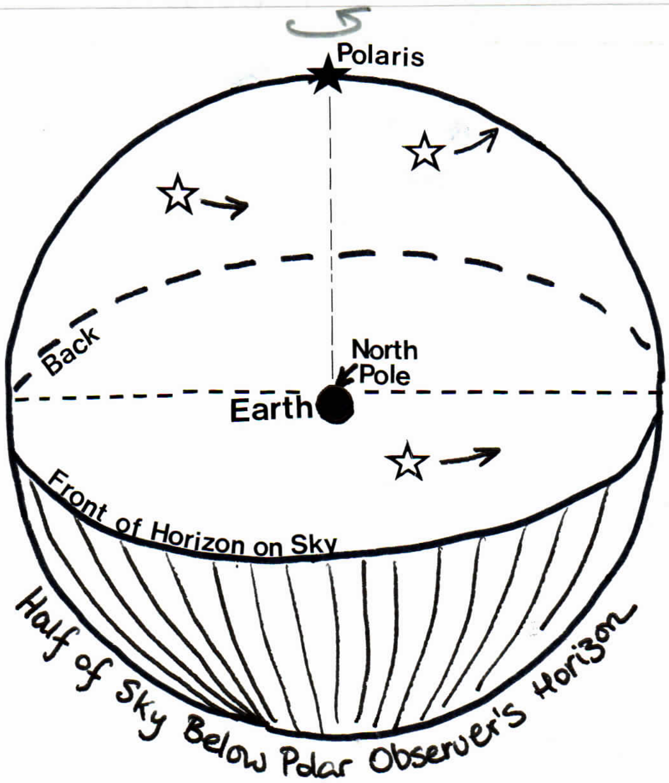


Fig. 4
Movement of stars as seen by observer at Earth's North Pole
(dotted part of Horizon lies behind diagram)

direction on the horizon) because it is a circumpolar constellation when seen from much of Europe and North America.

In the part of the sky that is not circumpolar, only a segment of any star's daily circle lies above the horizon, and if we face the Southern horizon while in Earth's Northern hemisphere we see the star tracks to be circles centred on an invisible point below it (Figure 5), the celestial South Pole.

We recognise today that the celestial North and South Poles are the directions in the sky towards which the rotation axis of the Earth points, when projected infinitely Northwards and Southwards from Earth (Figure 6), and that the daily cycle of the stars is simply the reflection of the Earth's eastwards rotation once every 24 hours. Our senses give no hint of Earth's motion however and do not deter us at all from concluding that, relative to the seemingly massive and rigid features of our horizon, the daily cycle of the stars is an endless, uniform, silent revolution as of a cold, distant sphere over our heads.

The ancients recognised that, unlike the Moon and the Sun, the stars that are not circumpolar rise and set at the same place on the horizon every time when observed from the same point on Earth (apart from a very slow phenomenon known as the polar precession, to be described later). Furthermore, it is apparently the same pattern of constellations that decorates the celestial sphere at all times (apart from very small motions of the stars relative to one another which take many centuries to become noticeable to the eye). The perfection and changelessness of the daily stellar cycle stands out among all other celestial cycles, and its philosophical interpretation will play an important role in what follows.

Interest in this daily stellar cycle was not just academic however. By measuring the angle between the celestial North Pole and the North point on the horizon below it an observer can infer his latitude on the surface of the Earth (Figure 7). The variation in size of the circumpolar region of sky between such places as Greece and north Africa, associated with the appearance of more southerly stars (such as the conspicuous bright star Canopus) as a traveller went South, encouraged the concept that the Earth itself had a curved surface. An observer familiar with the seasonal configuration of the constellations could also deduce the "time of night" from a glance at the starry sky near his horizon.

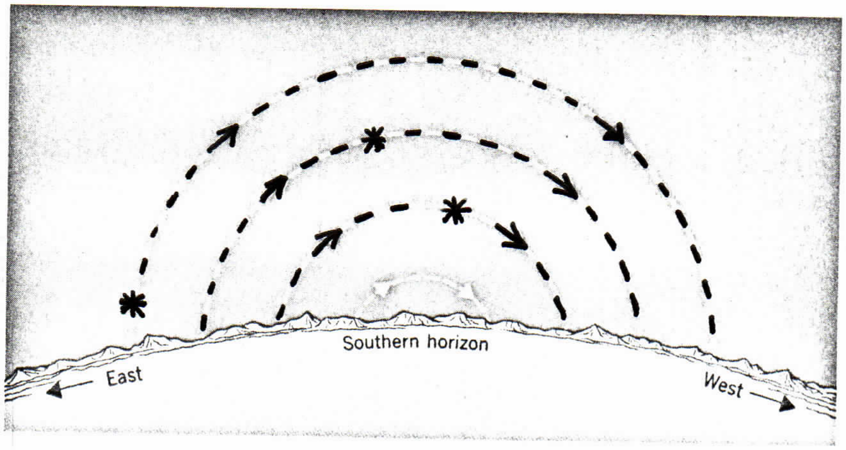


Fig. 5

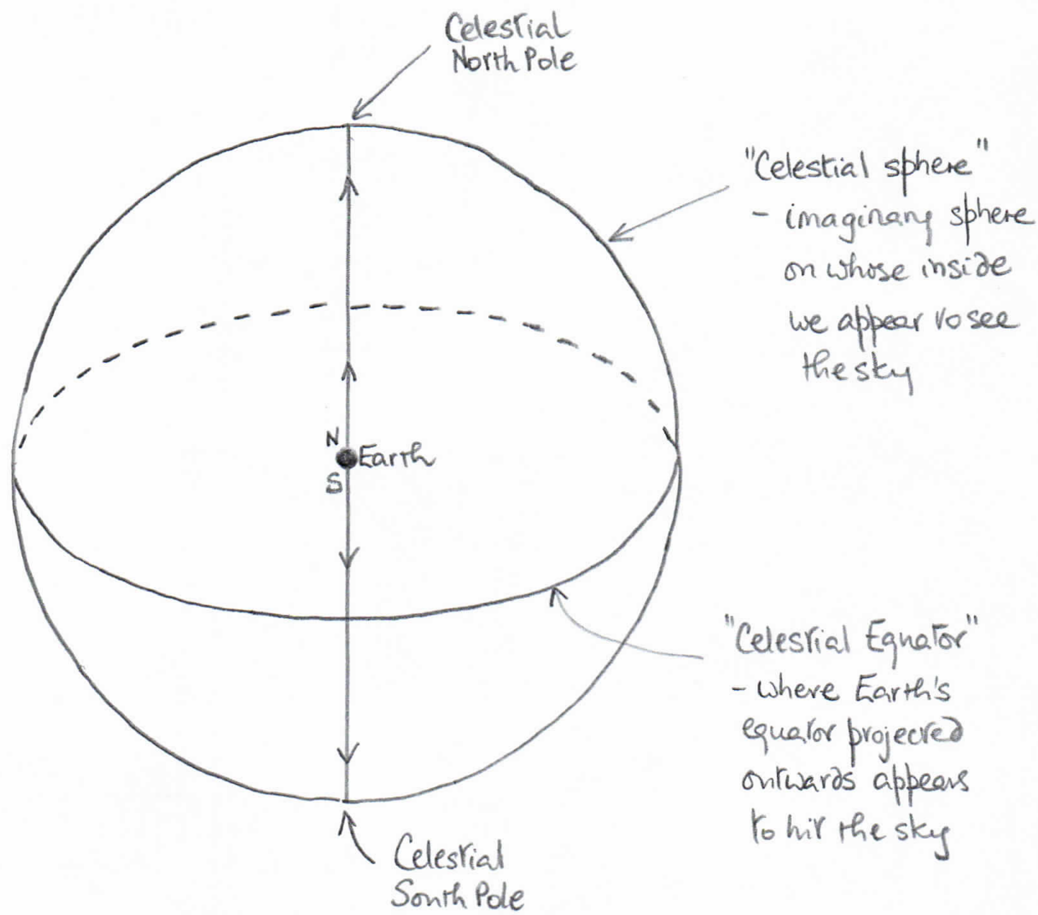
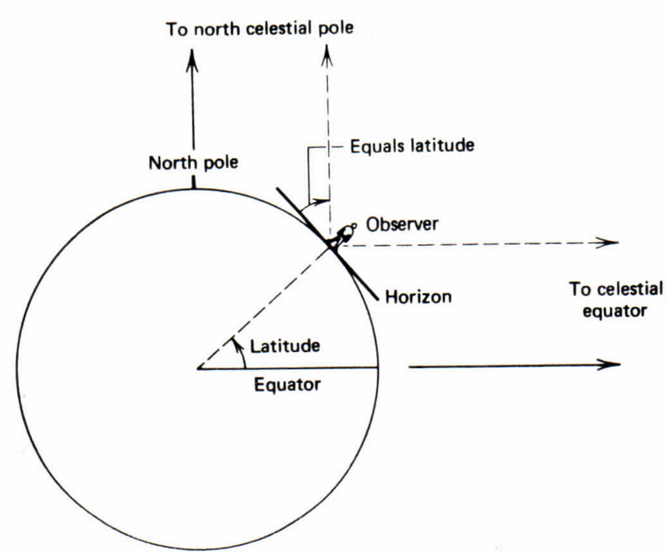


Fig. 6



The relationship between the north celestial pole, the terrestrial and the celestial equator, and the latitude of an observer.

Fig. 7

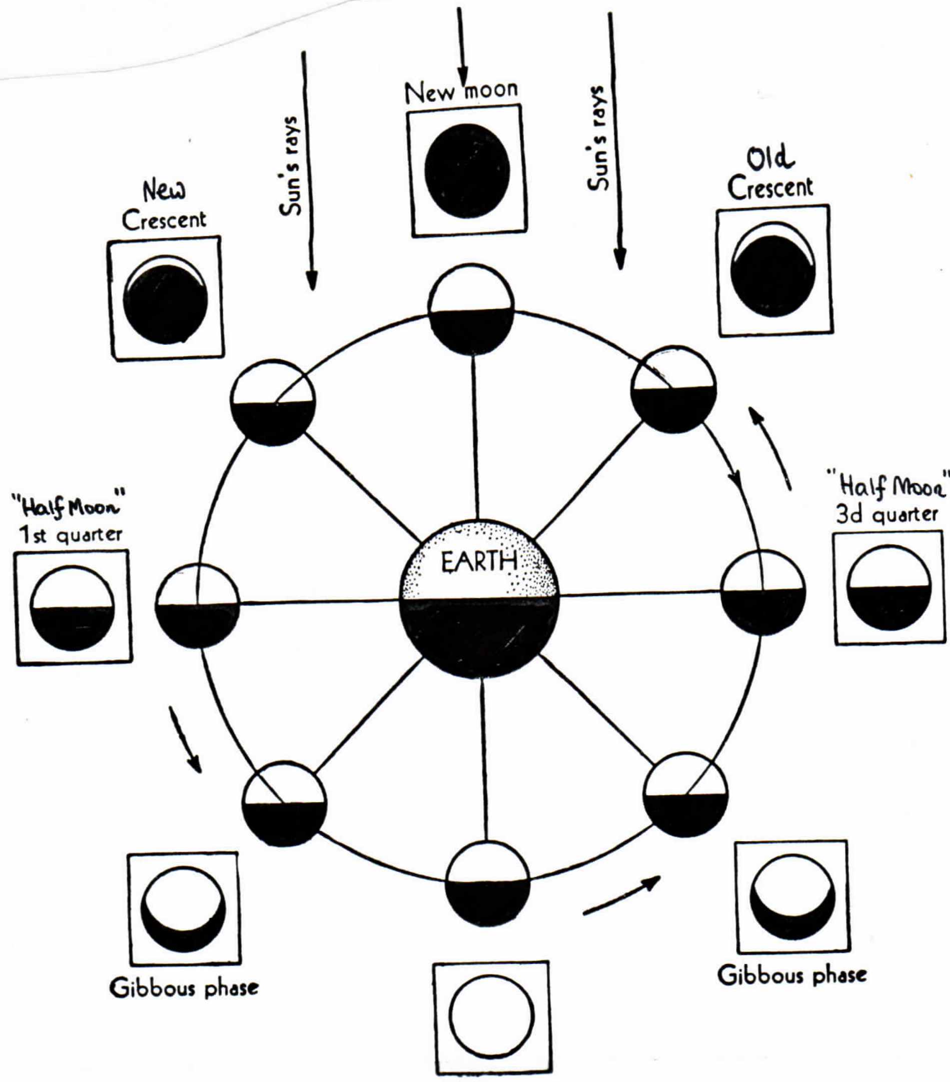
2. The monthly cycle of the Moon

Each time the Moon rises its appearance has changed, and the interval between successive Moonrises varies, averaging about 24 hours and 50 minutes. The changing appearance is called the cycle of phases, and repeats every 29½ days. While to modern Man this cycle is no more than a chance decoration of the night sky, to ancient Man it was most important for it brought about a tremendous variation in the amount of natural illumination at night.

The reason for this can be seen from Figure 8. The Moon is a ball made visible by reflected sunlight, and the cycle of its phases is the cycle of its position in the sky relative to the Sun. The 'New' crescent Moon is seen when the Moon is very close to the Sun in the sky. At this phase not only does the Moon cast very little light towards Earth, but it follows the Sun below the horizon soon after sunset leaving a truly dark starlit sky until the next morning twilight. About a week later however it is at the 'First Quarter' phase, 90° away from the Sun in the Sky. It is then high in the sky at sunset and does not set until around midnight. At 'Full Moon', about a further week later, it is approximately opposite the Sun in the sky and so rises at sunset, giving a brilliant illumination all night until it sets shortly before sunrise.

To a society for which the Moon, and not the Public Utilities Commission, is the bringer of nocturnal light, the cycle of phases was most important, and it should not be surprising that it was studied in great detail even thousands of years B.C. The Moon's light is not so bright that it prevents observations of the brighter stars in the sky around it, and Arab, Chinese, Indian and other early cultures divided the starry sky into "moon stations" about 13° apart along the Moon's apparent path against the stars. Each station was occupied on successive days by the Moon as it rose, and the keeping of continuous records showed that the Moon's position against the background stars repeated every 27 1/3 days; different cultures adopted 27 or 28 'moon stations' accordingly.

The time for the cycle of phases (29½ days) is longer than the time for the cycle of "moon stations" (27 1/3 days) because the phase cycle combines the apparent motion of the Moon with that of the Sun around the Earth, while the 'moon station' cycle combines that of the Moon with that of the stars. The phase cycle is easy to observe and can be used to keep track of time



As seen from Earth :-

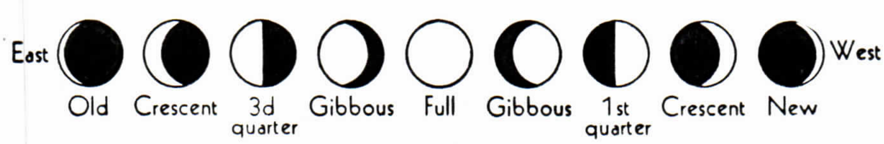
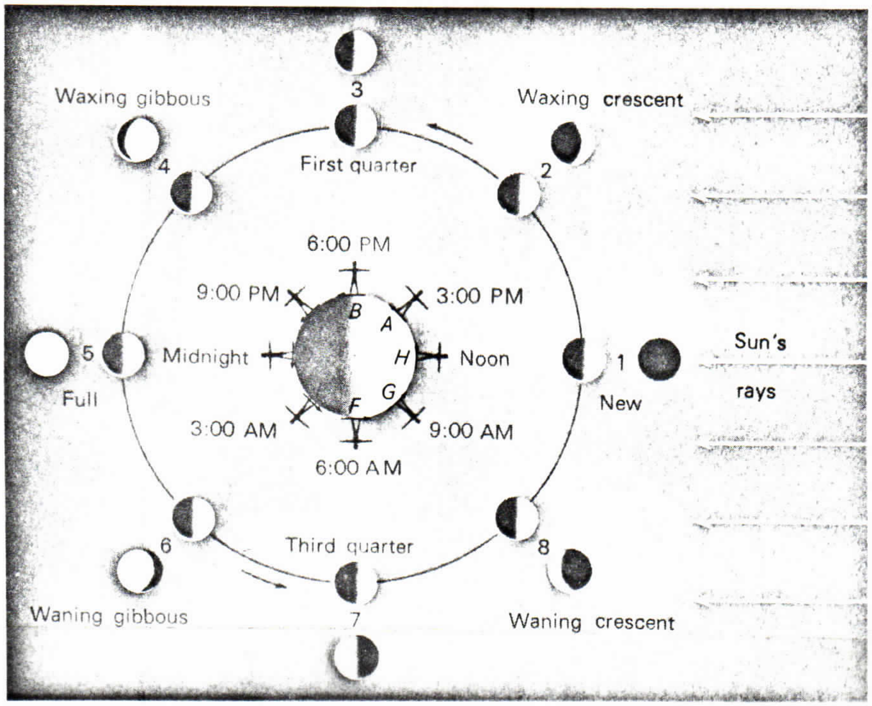


Figure 8



Phases of the moon and the time of day. (The outer series of figures shows the moon at various phases as seen in the sky from the earth's surface.)

throughout a 29- or 30-day period. It was therefore used as the basis of a lunar calendar, in which time was divided into 'months' ("moonths"), each new interval beginning with each 'New Moon'. The intervals corresponding to those between 'New', 'First Quarter', 'Full' and 'Third Quarter' phases gave rise to the division of months into weeks.

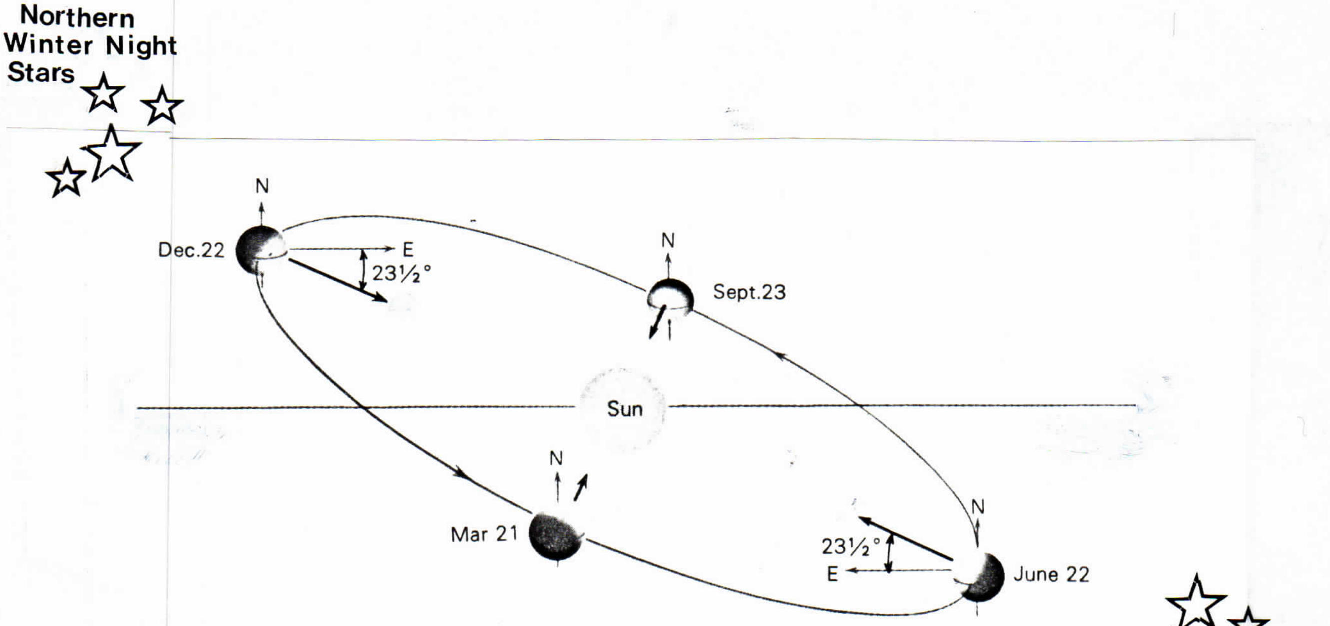
The lunar calendar is easy to keep track of by observation but has a very serious disadvantage. It falls out of step with the seasons, as we can see by considering the cycle of the Sun.

3. The yearly cycle of the Sun

The discordance between the lunar phase cycle and the cycle of moon stations emphasizes that the Sun also steadily changes position against the background of the stars, though not so obviously as does the Moon. By watching the darkening sky near the point where the Sun sets each night, a careful observer will notice that the Sun apparently drifts eastwards against the stellar background by about 1° per day - this is the origin of the degree as the unit of angle. The interval between successive appearances of the Sun against any given star group is 365.2422 days. If this cycle is used to define the 'year' as a unit of time, there is an immediate incompatibility with the length of the 'month': the year turns out to be 12.3344 months. After three years the beginning of a 'New Year' would therefore move into a different 'month' in a lunar calendar.

This would be unimportant were it not for the fact that the yearly cycle brings a cycle of warm and cold seasons, and with this a cycle of crop growth. While the easily-followed lunar calendar was adopted by most nomadic cultures, the development of agricultural societies focussed attention on establishing a satisfactory solar calendar which kept pace with the seasons.

The reason for the seasons can be seen from Figure 9. The yearly cycle of the Sun against the stars is understood today as the reflection of the Earth's annual motion around the Sun in orbit. The Earth's rotation axis is tilted approximately $23\frac{1}{2}^{\circ}$ from the perpendicular to the orbit, so that the Northern and Southern hemispheres are tilted alternately towards and away from the Sun as the Earth swings around it. When the Northern hemisphere is tilted towards the Sun, the Sun appears in the Northern half of the stellar sky as seen from Earth. It therefore rises North of East on the horizon and



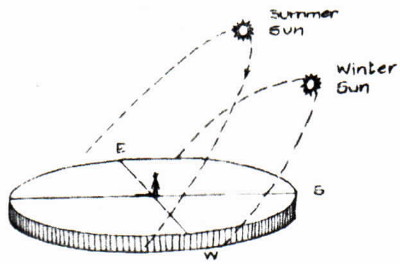
The seasons are caused by the inclination of the plane of the earth's orbit to the plane of the equator.

Fig. 9

sets North of West. More than half of its daily circle is then above the horizon, so there are more than 12 hours of daylight. When the Northern hemisphere is tilted away from the Sun, the Sun appears in the Southern half of the stellar sky, rises South of East, sets South of West, and is above the horizon for less than 12 hours each day. The extreme daily tracks of the Sun as seen by a Northern observer are indicated in Figure 10. On what we call June 22 in our modern calendar (the "Summer Solstice") the midday Sun is at its highest in the sky all year for such an observer. The long hours of daylight and nearly vertical midday illumination (Figure 11) combine to maximise solar heat input into the Northern hemisphere environment on this day. On December 22 (the "Winter Solstice") the situation is reversed; the Sun is lowest in the sky at midday and the daylight hours are shorter than the nighttime. This corresponds to the least heat input to the Northern environment. On both March 21 and September 23 the Earth's axis of rotation points neither towards nor away from the Sun (Figure 9). On these dates the Sun rises due East on the horizon and sets due West, so exactly half of its daily circle is above the horizon and half below and the hours of daylight equal those of night. These dates are known as the Spring and Fall Equinoxes. The modern "official seasons" of Spring, Summer, Fall and Winter are the intervals between the Spring Equinox and Summer Solstice, Summer Solstice and Fall Equinox, etc.

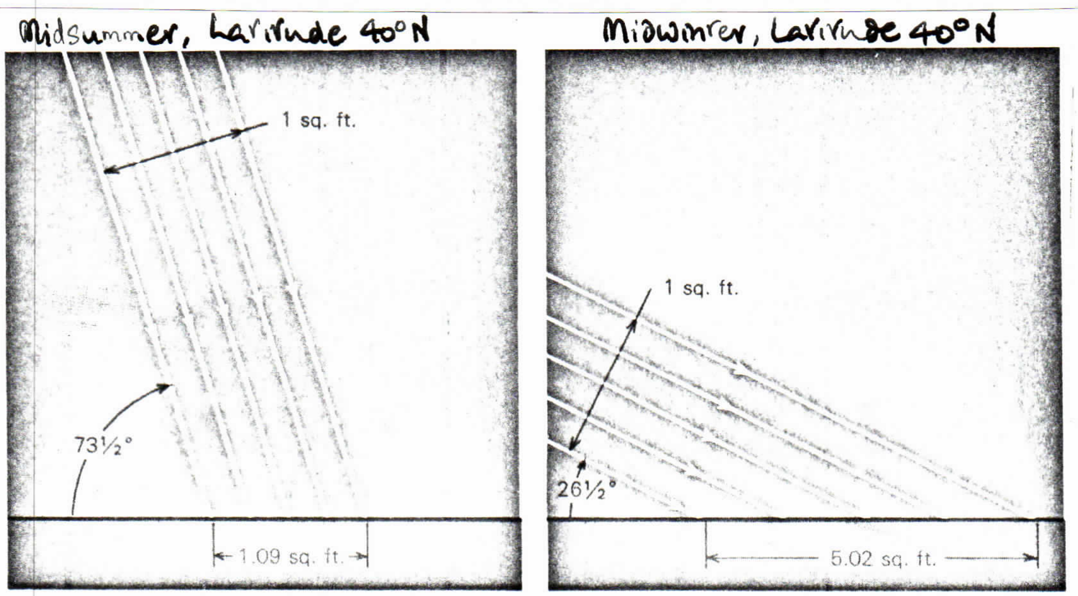
Keeping track of a solar calendar is not a trivial matter. One technique, evidently in use for some thousands of years B.C., is to select a convenient site as an 'observatory' and provide it with a marked-off horizon, e.g. a stone circle. Then by noting the places on the 'graduated horizon' where the Sun rose or set, the passage of the yearly cycle might be monitored. Observers using such stone circles would be in a position to notice that risings and settings of the Moon also migrated back and forth along an arc of the horizon, leading them to an understanding of still further celestial cycles, such as the cycles of eclipses.

Another technique for keeping track of a solar calendar uses the fact that away from the circumpolar region different stars are in the night sky at different times of year. The reason for this will again be evident from Figure 9 - the star groups which rise and set with the Sun provide an index to the time of year. For example, a Greek "Farmer's Almanac" of around 700 B.C. uses such a "heliacal" rising of the bright star group called the Pleiades:



(a) Path of the sun through the sky for one day of summer and one day of winter.

Fig. 10



Effect of the sun's altitude. When the sun is low in the sky, its rays are more oblique to the ground and are spread over a larger area than when the sun is high in the sky.

Figure 11

> "When the Pleiades are rising (at sunrise) begin your harvest and your ploughing when they are going to set (at sunrise). Forty days and nights they are hidden and appear again as the year moves round, when first you sharpen your sickle."

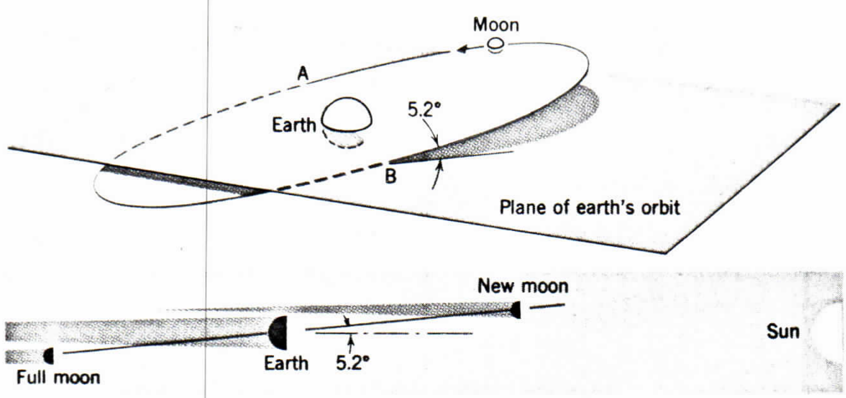
Development of a civil calendar within a society frees the individual from the need to make such observations to keep track of the time of year, and this task was attended to from earliest recorded times. Babylonian astronomers discovered that 235 lunar months almost exactly equalled 19 solar years, so that a simple lunar calendar system could be 'recycled' every 19 years; even greater accuracy of agreement with the seasons could be obtained by dropping one day from such a lunar system every sixteen years. Nevertheless, the inconvenience of having the seasons 'slipping' through the calendar months brought about revisions to such a system in agricultural societies, and calendars were adopted with "years" of 12 months alternately 29 and 30 days to match the lunar phase cycle, into which 'extra' months were inserted every two or three years to correct the seasonal slippage. The "leap months" became a political issue in Rome in the time of Julius Caesar when their insertion into a given year had become a matter of political expediency and corruption. Julius Caesar, on the advice of the Egyptian astronomer Sosigenes, then adopted a calendar reform dividng a 365-day 'year' into 12 unequal 'months' and inserting an extra day into the shortest month once every four years to make the average calendar year 365¼ days. This "Julian" calendar, adopted in 46 B.C., set the basic form of our modern calendar retaining in its "months" and "weeks" a memory of its strictly lunar predecessors. The solar year is however not 365¼ days exactly but 365.2422 days. By 1582 A.D. this difference had accumulated sufficiently to cause an 11-day slippage of the civil date relative to the seasons, so Pope Gregory XIII declared that among Catholic countries Thursday October 4 would be followed by Friday October 15 to 'reset' the system. Thereafter the so-called "Gregorian" calendar prevailed, in which century years are omitted as leap years unless divisible by 400. The resulting average length of the Gregorian calendar year is 365.2425 days, and the seasonal 'slippage' is reduced to less than one day in 3000 years.

4. The eclipse cycles

Peoples who recognised the Sun as the bringer of growth, and regulated their affairs in harmony with the celestial cycles must initially have regarded the disappearance of the Sun from the sky as an awesome event. For several minutes as the solar disc is blotted out a strange new light, the corona, shines around it, the air chills and animals and plants prepare for night. Only careful keepings of records of the circumstances of eclipses brings the reassurance that they are explicable and predictable.

Even casual observers would notice that eclipses of the Sun occur only when the Moon is in the New phase, and those of the Moon when it is in the Full phase. This alone tells that the Moon is responsible for the solar eclipse, and the Earth's shadow for the lunar. We do not see two eclipses each month however. Study of the paths of Moon and Sun against the stars reveals that these two paths are circles inclined to one another by 5°.2, so that when the Moon is towards the Sun at New Moon it can actually be as much as 5°.2 above or below it in the sky (Figure 12). Under such circumstances the Moon's shadow does not strike the Earth and there can be no solar eclipse visible for Earth. Similarly, there need not be a lunar eclipse at every Full Moon.

Eclipses can occur only at New or Full Moons at which the Moon is near one of the two intersections of its apparent path with that of the Sun. For this reason the apparent path of the Sun against the stars is called (Fig. 13) the <u>ecliptic</u>. The two intersections of the Moon's path with the ecliptic are called the <u>nodes</u> of its orbit. If the lunar orbit remained fixed in space for all time, the Moon would be at each of the nodes exactly once every cycle of "moon stations" or 27.3 days (the <u>sidereal month</u>). In fact the plane containing the Moon's orbit wobbles in space completing one revolution relative to the stars every 18.6 years. This means that the nodes appear to travel around the ecliptic once every 18.6 years and the Moon is at a given node every 27.21 days (the <u>draconitic month</u>). The circumstances of an eclipse can be repeated only at an interval reconciling this cycle with the 29.53-day cycle of phases (the <u>synodic month</u>). It turns out that 223 synodic months are very nearly equal to 242 draconitic months, both periods being about 6585 1/3 days (about one and one-half weeks longer than 18 years). This cycle, known as the Saros cycle, was known before 500 B.C. by the Chaldaean astronomers.



The tilt of the plane of the moon's orbit to the plane of the earth's orbit.

Unfavorable conditions for an eclipse.

Fig. 12

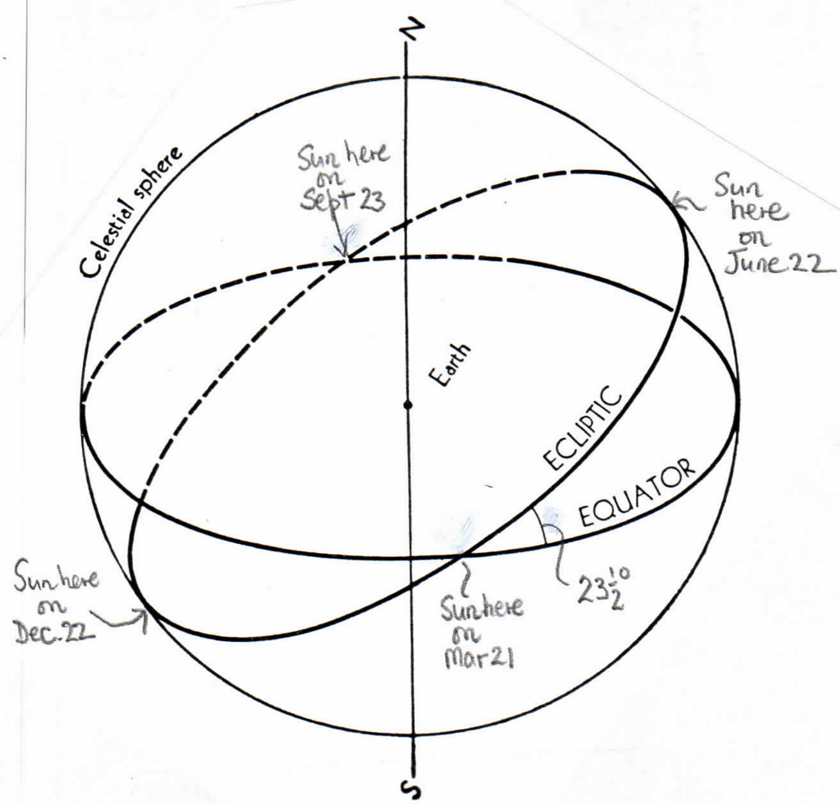


Fig. 13

There are other numerical relations between the draconitic and synodic months that lead to approximate eclipse cycles; the Tritos (135 synodic months = 146½ draconitic months = 3986.6 days) and the Inex (358 synodic months = 388½ draconitic months = 10571.95 days), and others. Discovery of such cycles stimulated efforts at eclipse prediction, freeing Man from fear of the phenomenon though doubtless encouraging those who could make the predictions to place their fellows in awe of them instead.

In various societies the astronomers became powerful civil servants or priests, and the cultivation of astronomical knowledge became commonplace. Early attempts to construct cosmologies, or theoretical models of the world, therefore paid considerable attention to astronomical phenomena.

Summary

Even primitive observers were drawn to careful study of the skies by practical considerations. Solar, lunar and stellar cycles have been documented and turned to practical use since the earliest recorded writings of Man. The importance of keeping track of celestial cycles, both to predict regular events such as the passage of the seasons, and exceptional events such as eclipses, gave early status to astronomical knowledge and encouraged careful observations.