Chapter 3

Diurnal Motion, Time and the Calendar

3-A. Diurnal Circles

A casual inspection of the sky reveals that all celestial objects rise on the eastern horizon, cross the local celestial meridian, where an object's altitude is a maximum, and set on the western horizon. This is an apparent motion caused by the rotation of the Earth around its axis and is referred to as the diurnal rotation of the celestial sphere. The angular rate of rotation of the Earth is 15 degrees per hour, since the Earth rotates through 360 degrees in 24 hours. Hence, celestial objects appear to move in the sky along paths at this rate, but in the opposite direction, that is, from east to west. The path that an object follows across the sky from east to west sky because of this motion is called its **Diurnal Circle**.

Diurnal circles are the apparent paths that objects appear to follow
in the sky as a result of the rotation of the Earth around its axis.

Now the right ascension and declination of an object are not affected by the diurnal rotation of the celestial sphere, but altitude and azimuth are. Since the sky appears to turn around an axis through the celestial poles and in a direction parallel to the celestial equator, **a diurnal circle is actually the same as the object's parallel of declination.** Thus all objects with the same declination trace out the same diurnal circle. A few of these circles are shown in Figure 3-1.
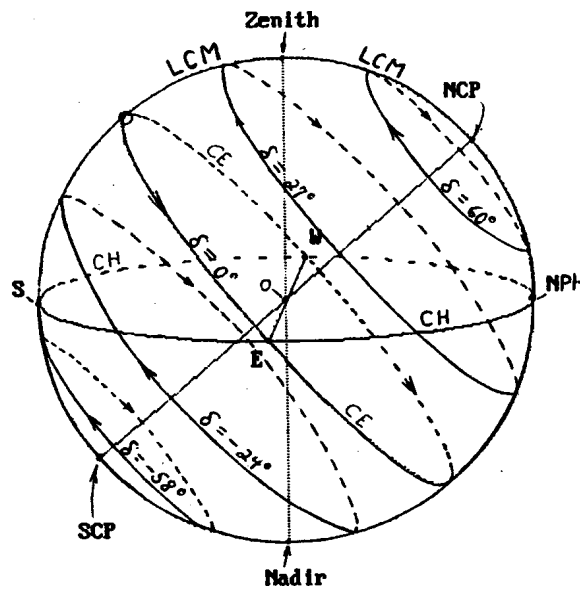

Figure 3-1. Diurnal circles drawn on the celestial sphere for
several different declinations, as seen from latitude 40° N.

Notice that diurnal circles make an angle with the horizon but they are all parallel to one another. From the geometry of the situation (see Fig. 3-1), it can be shown that the celestial equator (CE) intersects an observer's celestial horizon at the east and west points. Thus the diurnal circle that passes through the east point of the horizon and west point of the horizon is the celestial equator (CE). Recall that every point on the celestial equator is 90° from either of the two celestial poles. Therefore, the angle that the celestial equator makes with the horizon is always equal to 90° minus the observer's latitude (90° - φ).

The time that an object spends above the horizon depends essentially on where it is located with respect to the celestial equator, i.e., its declination. Half of the equator is above the horizon and so any object on it (declination 0°) is above the horizon for 12 hours and below the horizon for 12 hours. Such an object rises at the east point and sets at the west point.

Those objects with declinations between 0° and +90°, rise in the northeast, remain above the horizon for more than twelve hours and set in the northwest. Those objects with declinations between 0° and -90°, rise in the southeast, are above the horizon for less than twelve hours and set in the southwest.

Now the horizon system of circles is fixed with respect to an observer. Therefore, all the reference circles of this system do not share in the rotation of the celestial sphere. This means the altitude and azimuth of an object on the celestial sphere both change with time and location, but remember, the right ascension and declination do not. Hence, the horizon system is only useful for locating objects on the celestial sphere at a given location on the Earth and at a given instant of time. So, as the celestial sphere appears to turn around its axis, objects in the sky move relative to the horizon and the local celestial meridian (LCM).

As we saw in the previous chapter, **the axis of rotation lies in the plane of the local celestial meridian and it is tilted relative to the celestial horizon by an amount equal to the observer's geographic latitude.** When an object crosses the upper local celestial meridian, it is said to be at **upper transit (UT).** At upper transit the object is at its greatest distance above the horizon, that is, its altitude is a maximum. When the object crosses the lower local celestial meridian, it is said to be at **lower transit (LT).** At **LT**, an object is at its minimum angular distance (in the algebraic sense) from the horizon. When an object is below the horizon, it's angular distance from the horizon, or altitude, is assigned a negative value.

Objects make one upper transit and one lower transit each day. For an observer in the Northern Hemisphere, both upper and lower transit will occur above the horizon for stars located near the north celestial pole. That is, for objects with high declinations. Such objects will have their diurnal circles entirely above the celestial horizon and, therefore, can be seen every night. Such objects are called **circumpolar stars of perpetual apparition** (stars that are always visible), since they circle around the pole star.

By symmetry, for this same observer, there will be a range of declinations for stars near the south celestial pole that never rise above the horizon. That is, their diurnal circles are completely below the horizon and such an object can never be seen at that latitude. These stars that never rise are called **circumpolar stars of perpetual occultation**.

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**Which objects are circumpolar and which are not depends
on the observer's latitude and the declination of the object.**

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Objects located on the celestial equator rise exactly at the east point, while objects north or south of the celestial equator rise to the north or south of the east point. It is very important to realize that objects, which rise exactly at the east point, must set exactly at the west point. Likewise, objects that rise in the northeast set in the northwest and objects that rise in the southeast set in the southwest.

As discussed previously, the time that an object spends above the horizon depends essentially on where it is located with respect to the celestial equator, i.e., its declination. Half of the equator is above the horizon and so any object on it (declination 0°) is above the horizon for 12 hours and below the horizon for 12 hours. Such an object rises at the east point and sets at the west point.

3-B. Hour Angle

Another important angle related to diurnal motion and time is an object's **hour angle**.

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**Hour Angle (HA) is the angular distance of an object
measured westward from the Local Celestial Meridian.**

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It is sometimes convenient to use positive and negative numbers to describe the position of an object with respect to the Local Celestial Meridian. Some authors refer to such an angle as the **meridian angle, t.**

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**When the object is west of the Meridian, t is denoted as
positive and when it is east of the Meridian t is negative.**

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But, it is often convenient to use the hour angles that are negative or positive also, contrary to the above definition.

The hour angle or meridian angle changes from negative to positive when the object crosses the Upper Local Celestial Meridian, moving east to west. As was noted above, when an object crosses the upper LCM, its altitude is a maximum and the object is said to be at **Upper Transit** (UT). The hour angle changes sign again when the object crosses the lower Local Celestial Meridian twelve hours later. At this time, the altitude of the object is a minimum and it said to be at **Lower Transit** (LT).

3-C. The Apparent Annual Motion of the Sun

A star always rises and sets at the same place on the horizon and, hence, it is above the horizon for the same amount of time every day of the year. That is, a star traces out the same diurnal circle every day because its declination does not change. This is not true, however, for the Sun, Moon, and planets, because these objects move with respect to the background of "fixed" stars, i.e., their declination changes with time.

The changing declination and right ascension of the Sun is caused by the fact that Earth revolves in orbit around the Sun with its axis of rotation tilted with respect to the plane of its orbit. See Figs. 3-2 and 3-3. The amount of this tilt is 23.5° as measured from a line perpendicular to the Earth's orbital plane. This line pierces the celestial sphere at two points called the **north ecliptic pole and south ecliptic pole.** In the figures, these two points are designated as **NEP** and **SEP.**
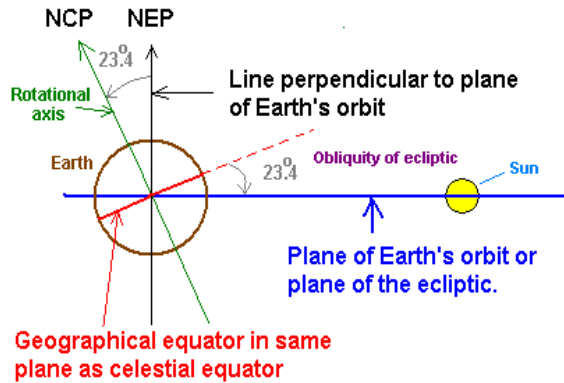
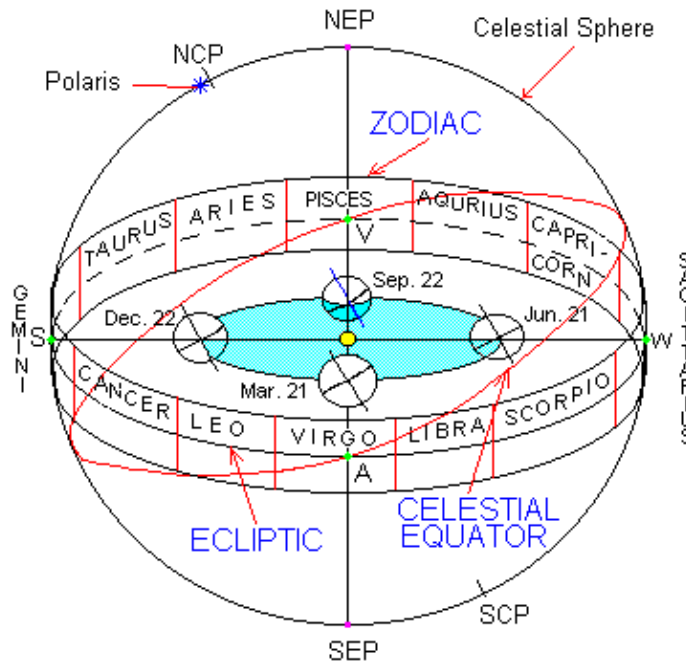Fig. 3-2. A schematic, not to scale, showing the meaning of the obliquity of the ecliptic.

Figure 3-3. The relationship between the plane of the Earth's orbit, the ecliptic, the Zodiac, and the celestial equator. The position of the Earth in its orbit around the Sun is shown for four important seasonal dates of the year.

As the Earth revolves in its orbit around the Sun, its axis of rotation remains parallel to itself. That is, the axis always points towards the north celestial pole (**NCP**). For an observer on the Earth, the Sun then appears to move in a circle around the celestial sphere eastward with respect to the **fixed stars.** This circle is called the **ecliptic** and is labeled VSAW in Fig. 3-3. Note that the ecliptic lies in the plane of the Earth's orbit. Thus the ecliptic is inclined to the

celestial equator by 23.5°. This angle is referred to as the **obliquity of the ecliptic**. Therefore, as the Sun appears to move around the ecliptic over the course of a year, its angular distance from the celestial equator (declination) changes. The 2 points of intersection of the ecliptic and the celestial equator are called the **equinoxes**. Now, the Earth takes 365.2564 days to complete a 360° orbit around the Sun. Therefore:

In the sky, the Sun appears to move eastward along the ecliptic
at the rate of about one degree per day, relative to the "fixed stars."

This apparent motion of the Sun along the ecliptic is merely a reflection of the Earth's revolution. On or about March 21, the Sun appears to cross the celestial equator moving from south to north. The Sun is then at the point labeled V in Figure 3-3, which is called the **vernal equinox.** The Sun reaches its maximum northerly declination (+23.5°) on or about June 21. It is then at the point labeled S, which is called the **summer solstice**. The Sun then crosses the celestial equator, moving from north to south on or about September 22 and is at the point labeled A, called the **autumnal equinox.** The point where the Sun reaches its maximum southerly declination (-23.5°) is the **winter solstice,** W**.**

Hence, twice a year the Sun rises exactly at the East Point of the horizon and sets exactly at the West Point. These are the days when the Sun is at the equinoxes. On these two days, the Sun is above the horizon for twelve hours and below the horizon for twelve hours. See the diagram below, which depicts the diurnal circles of the Sun as seen from Los Angeles.   So, near mid-latitude in the summer, the Sun rises in the northeast and sets in the northwest, with the daylight portion of the day longer than the nighttime portion. The day of the year with the longest daylight period occurs about June 21, when the Sun is at the **Summer Solstice**. During the winter, the Sun rises in the southeast and sets in the southwest, with the amount of daylight hours is less than the amount of nighttime hours. The day of the year
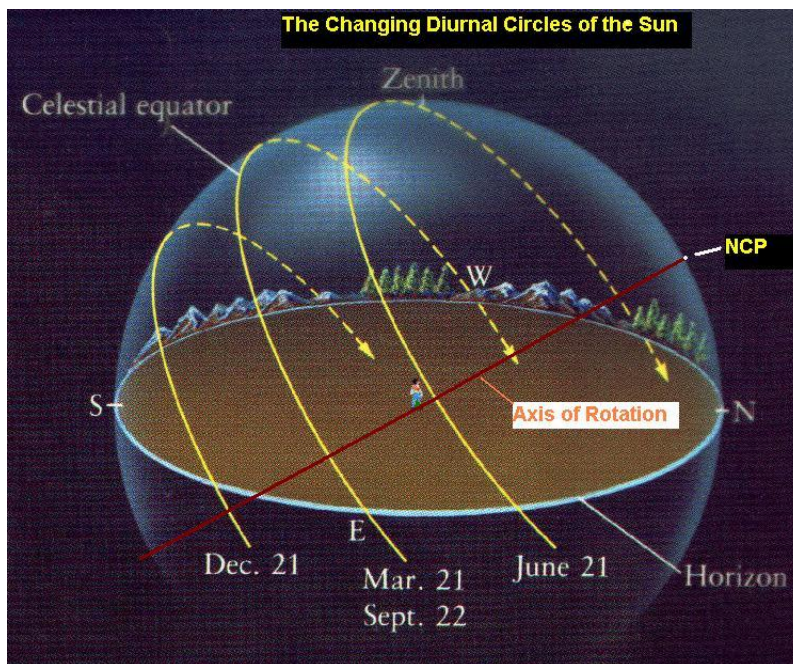
with the shortest amount of daylight occurs about December 22, when the Sun is at the **Winter Solstice**. All of these things are related to the fact that the diurnal circle of the Sun slowly changes from one day to the next, which means the declination of the Sun changes slowly throughout the year.

The equinoxes and solstices are associated with the above dates only in the sense that the Sun is located at these points on or about those dates. Actually these dates may change by a few days from one year to another. The equinoxes and solstices should be thought of as positions on the celestial sphere rather than as specific dates. For example, the vernal equinox is a point on the celestial sphere located in the constellation of stars called Pisces. Like other points on the celestial sphere, an observer on the Earth sees the solstices and equinoxes to execute diurnal circles that depend on the declination of these points. The vernal equinox rises at the east point of the horizon and sets at the west point of the horizon every day throughout the year. Hence, when the Sun is at the vernal equinox, it also rises at the east point and sets at the west point.

The following table lists the declinations and right ascensions for some important points in the sky. A "**U**" means undefined. Note that objects on the celestial equator have declinations of zero degrees and that objects south of the

celestial equator have negative declinations. The right ascension and declination of the Sun's position vary as it moves along the ecliptic from one point to another as shown in the above table. The time required for the Sun to cycle through its coordinates, that is, the time it takes the Sun to go once around the ecliptic from the vernal equinox back to the vernal equinox is called the **year of the seasons or tropical year and has a length of 365.2422 days.** The time it takes for the Earth to revolve 360 degrees in its orbit around the Sun is called **the Sidereal Year and has length of 365.2564 days**.

A TABLE OF SOME DECLINATIONS AND RIGHT ASCENSIONS

POINT	DECLINATION (Degrees)	RIGHT ASCENSION (Hours)
VE	0.00	0.00
SS	+23.5	6.00
AE	0.00	12.00
WS	- 23.5	18.00
NCP	+90.00	U
SCP	- 90.00	U

The latter is longer than the tropical year by about 20 minutes because of the precession of the Earth's axis of rotation (See section 3-I and Chapter 4 on precession). The Moon cycles through its coordinates in one sidereal month or 27.33 days. The time required for a planet to do this depends on its period of revolution.

Because the orbits of the planets of our Solar System lie nearly in the same plane as the Earth's orbit, the planetary orbits are circles in the sky close to the ecliptic. The belt of the sky, centered on the ecliptic and where most of the planets are observed, is called the **zodiac.** The ancients organized the stars that are located in this belt into twelve constellations known as the **zodiacal constellations**. The Sun moves from one zodiacal constellation into the next one in about one month. Visualize this in Figure 3-3.

3-D. Time by the Sun

Time is the interval between two measurable events, such as the ticks of a clock or the beat of a heart. Before the invention of clocks, people often used the apparent motion of the Sun across the sky to tell time. Time using the visible, apparent, or real Sun is called local apparent solar time and abbreviated as **LAT**. Local apparent solar time is defined to be the hour angle of the Sun ($HA_\odot$) plus twelve hours.

$$LAT = HA_\odot + 12:00$$

This is the time indicated on a sundial, that is, it is time by the position of the Sun in the sky relative to one's local celestial meridian. The event taking place here is the upper transit of the Sun. A long time ago it was decided that this interval should be called a day and that it consisted of exactly 24 hours.

However, LAT is not the time we use today on our clocks. There are two reasons for this. First, the real Sun moves at a varying rate along the ecliptic as a result of the Earth's variable speed in its elliptical orbit around the Sun. This means that the interval between upper transits of the Sun changes throughout the year. Secondly, the obliquity of the ecliptic also causes the length of the apparent solar day to be different at different times of the year. Hence, keeping time by the real Sun is not practical.

The time we use on our clocks is called zone time, **ZT**. Everyone living within a specified zone of longitudes agrees to use the same time on their clocks, regardless of the location of the Sun in the sky. This is necessary in a world where people travel relatively large distances very quickly. Zone time uses what is called the local mean solar time, **LMT**, of the central meridian of a time zone.

Everyone has a unique LMT that depends on their longitude**. LMT** is time kept by the position in the sky of a fictitious object called the **Mean (or average) Sun** that moves at a uniform rate around the celestial equator instead of the ecliptic.

LMT is the hour angle of the Mean Sun, as seen from a given longitude, plus 12 hours

Now we can define zonetime:

**ZT is the hour angle of the Mean Sun, as seen from
the central meridian of a time zone, plus 12 hours.**

The amount that one's LMT differs from their zonetime depends on how far you are from the central meridian of your time zone. For the Eastern Time Zone, the central meridian is 75° W. of the prime meridian at Greenwich, England. If you are located east of a central meridian, such as Boston is in the Eastern Time Zone, your LMT is ahead or later than the zone time by several minutes. On the other hand, if you live in Detroit, which is also in the Eastern Time Zone but west of the central meridian, your LMT is about 22 minutes behind or earlier than EST. TCNJ is located about 0.25 degrees to the east of the central meridian of the Eastern Time Zone. Hence, EST is 1 minute earlier than the LMT at TCNJ.

Most astronomical handbooks and almanacs list celestial events for the **Greenwich Mean Time, GMT,** at which they occur. Greenwich Mean Time is also called **Universal Time**. To convert GMT to one's ZT, one adds the zone correction number which is -5^h for the eastern standard time zone, or -6^h for the central time zone, etc.

The amount that one's LMT differs from one's LAT depends on the time of the year. That is, sometimes the Mean Sun is ahead of the real Sun and sometimes it is behind the real Sun, depending on the real Sun's declination and how fast the Earth is moving in its orbit. The LAT minus the LMT is a number that is called the Equation of Time and abbreviated as **ET**.

$$ET = LAT - LMT$$

This is a number that expresses how much the mean Sun is ahead or behind the real Sun. That is, ET is a number that is algebraically added to the LMT to get the LAT. The possible values for ET range from $+17^m$ to -14^m. How the values of ET changes throughout the year is shown in the above diagram to the right.

Equation of Time = Apparent Time — Civil Time
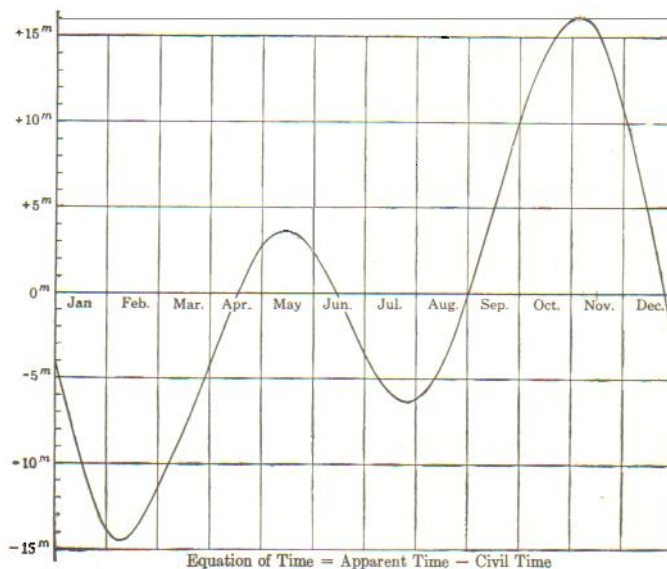
Because we use zonetime or LMT rather than LAT on our clocks, the earliest sunset occurs about December 8 rather than the day of the winter solstice. See if you can notice this in December. Similarly, the latest sunrise is on January 5 rather than the day of the winter solstice. There is a similar effect for sunrise and sunset near the summer solstice.

3-E Sidereal Time

Astronomer's use another kind of time called Sidereal Time. One's local sidereal time, or **LST**, is defined as the western (+) hour angle of the vernal equinox, that is, the time elapsed since the last upper transit of the VE. Therefore, it can never be a negative number.

$$LST = + HA_{VE}$$

The local sidereal time (LST) is also the right ascension of any object making upper transit. Sidereal time is time by the stars rather than by the sun. A clock that keeps sidereal time is used by astronomers to locate objects with a telescope. A useful relation between the LST and the RA and HA for any object (star, Moon, or planet) is:

$$LST = RA + t$$

Since the real and mean suns have a motion of about 1° per day eastward with respect to the fixed stars, the solar day is longer than the sidereal day by about 4 minutes of sidereal time. This is caused by the revolution of the Earth in its orbit.

There are 24 hours of solar time in a solar day and 24 hours of sidereal time in a sidereal day. Hence the two kinds of hours are not the same length. The sidereal hours are slightly shorter than the solar hours. This means the sidereal clock runs faster than the solar clock. However, the sidereal clock keeps track of the true rotation of the Earth on its axis, that is, the time for the Earth to rotate through 360°. Remember, the length of the solar day is complicated by the revolution of the Earth.

The sidereal clock and the solar clock agree on one day of the year and that is the day of the autumnal equinox. That is, when the Sun is at the autumnal equinox, its RA is 12:00, and since the LST is the RA of an object at UT, the

LST is 12:00 at noon on the day of the autumnal equinox. Thereafter, the sidereal clock gains approximately 4 ($3^m 56^s$) minutes per day on the solar clock.

Sample Problem:

At what EST will M1, the Crab Nebulae, make upper transit at TCNJ on September 15?

Solution:

First we need to find the RA for M1. This may found via the internet or a star chart. The answer is $5^h 34.5^m$. Then we need to find the number of days between Sept. 23 (this happens to be the date of the autumnal equinox in 2011) and Sept. 15. The answer is 8. So 8 days x 4 min/day = 32 min or 31.5 minutes to be more exact. But the sidereal clock in this case is going to be behind the apparent solar clock by this amount and will catch up to the solar clock on Sept. 23rd.

Now when M1 is at UT, the LST = RA of M1 = 5:34.5. On Sept. 15, the solar clock is ahead of the sidereal clock by 31.5 minutes. So the LAT = 5:34.5 + 0:31.5 = 6:06.0. Now we must apply the equation of time to find the LMT. From the chart above this is about +4^m. Hence, LMT = LAT – ET = 6:06 – 0:04 = 6:02. (we are using a 24 hour clock here, so this in the morning) Corrections must then be made for longitude and the fact that we may be using daylight saving time.

3-F. Spherical Trigonometry

The distance between any two points in the sky is an angle that is represented by an arc between these 2 points on the celestial sphere. See Chapter 1. This arc is always a section of a great circle. Very often in astronomy we would like to compute such a distance by setting up a spherical triangle in the sky that connects 3 points.

Consider a general spherical triangle on the celestial sphere that connects any three points A, B, and C, as depicted in the next figure. The sides of the triangle are a, b, and c. Though they are sides, they are also angles. Such a triangle also includes 3 angles, such as, BAC. We shall refer to this angle simply as A. The other two included angles are B and C.

Without proof, we give here the three most important relations for a spherical triangle. The proofs may be found in Smart (1965) or Binnendijk (1960). For the general triangle shown, the Law of Sines is:

$$\sin a / \sin A = \sin b / \sin B = \sin c / \sin C \qquad (1)$$

The Law of Cosines is:

$$\cos a = \cos b \cos c + \sin b \sin c \cos A. \qquad (2)$$

The Relation Between Two Angles and Three Sides is:

$$\sin a \cos B = \sin c \cos b - \cos c \sin b \cos A. \qquad (3)$$

Of course, permutations of the sides and included angles in the last two relations are valid.

3-G. Solving the Astronomical Triangle

An example of solving such triangle is done when wants to know what time an object will rise, set, or have any hour angle. For example, the angle **t** in the next figure is the meridian or hour angle of an object (**t** is the included angle **ZPS**). The side **z** is the zenith distance or complement of the altitude, $90° – h$, and the arc between the pole, P, and
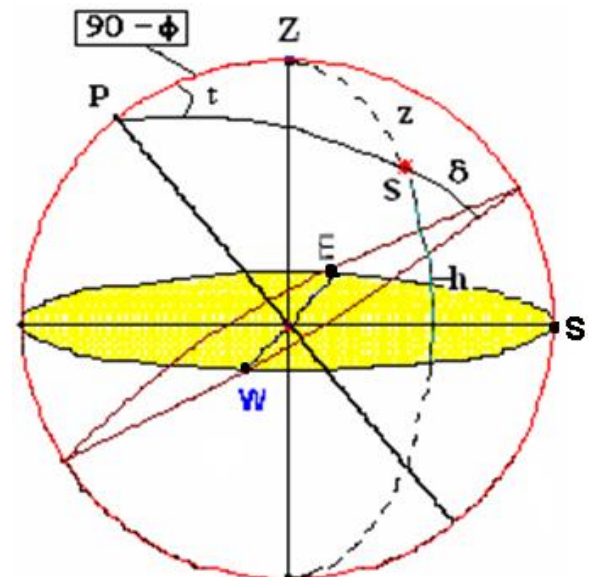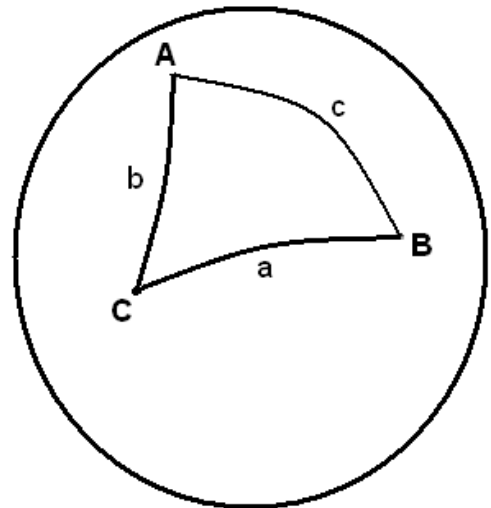
some object, **S,** is $90^o - \delta$. As in plane trigonometry, if we know any three parts of the triangle, we can solve for any of the other parts.

Let us say we want to find out the hour angle of the Sun when it sets. Solving the triangle for **t** will enable us to calculate the apparent solar time when the Sun sets, since

$$LAT = HA_{\odot} + 12:00. \tag{4}$$

To do this we need to know the declination, δ, of the Sun on a given day and the observer's latitude, ϕ. Hence, the arc $(90 - \phi)$ is assumed known. So, using the proper equation, we can solve for **t**. This may be done using equation (2) with $A = t$, $a = 90^o - h$, $b = 90^o - \phi$ and
$c = 90^o - \delta$. Substituting these parameters into (2) we obtain:

$$\cos (90^o - h) = \sin h = \sin \phi \sin \delta + \cos \phi \cos \delta \cos t. \tag{5}$$

Here we have used the relations $\cos (90^o-x) = \sin x$, and $\sin (90^o-x) = \cos x$. Now solve (5) for $\cos t$ and we have:

$$\cos t = [\sin h - \sin \phi \sin \delta] / \cos \phi \cos \delta \tag{6}$$

Nominally, we want h to be zero, so (6) simplifies to:

$$\cos t = [- \sin \phi \sin \delta] / \cos \phi \cos \delta$$

$$\cos t = - \tan \phi \tan \delta \tag{7}$$

Hence, the meridian angle of an object when it sets depends only on the observer's latitude and the declination of the object. When evaluating t, one must be wary of the quadrant of the angle. When using (4) to compute the time of sunset, remember to apply the equation of time when finding local mean time or civil time and then correct for longitude to obtain zone time.

In the above derivation, one assumes the object is a point source. For stars this is valid but for extended objects such as planets and the Sun, this is not valid and one must decide what is meant by rising and setting. For example, for sunset one must decide what point on the Sun is on the horizon. This is usually taken as the last point on the upper limb of the Sun to be visible.

Assignment 3-G 1:

Find the zone time the center of the Sun sets at latitude 40° N. on the day of the winter solstice. The value of the equation of time may found from the graph presented above in section D of this chapter. Then, we may write a program that does this for any values of the input variables.

For a more precise determination of sunset, one should also allow for refraction in the atmosphere. The amount of refraction is a rather uncertain amount because it depends on the temperature and density of the Earth's atmosphere and these are variables.

Do problem 3-G.2

3-H. The Anomalistic Year

The major axis of the Earth's elliptical orbit around the Sun is also known as **the line of apsides**. The line of apsides connects the perihelion and aphelion points of the Earth's orbit. Gravitational perturbations of the Earth's orbital motion are caused by the other planets. One of the results is to cause the line of apsides to rotate in the plane of the orbit eastward, that is, counterclockwise when viewed from the north ecliptic pole. The time for the Earth to revolve in its orbit from perihelion to perihelion is called the anomalistic year. **The anomalistic year has a length of 365.25964 days.**

3-I. History of the Calendar

The calendar used today traces its origin back to Rome. The old Roman calendar had 10 months and the last four months each had a name indicating what month of the year it was. For example, December was the tenth month. January and February were eventually added to the beginning of the old Roman calendar, but parliamentary records in England from 1750 indicate that, at least in that country, January and February were the last two months of the year. In any event, the old Roman calendar was variable in length and the date of the vernal equinox kept occurring on different dates in March. Julius Caesar attempted to make the Roman calendar more uniform and useful and consulted with the Greek astronomer, Sosigenes of Alexandria, on how to develop a new calendar that always had the same number of days and kept the vernal equinox occurring on the same date, March 25, in every year. By imperial decree, the new calendar became effective on January 1, 45 BC and became known as the Julian Calendar. It was probably designed to approximate the tropical year, which was recognized by Hipparchus, c. 150 BC. The Julian calendar has a regular year of 365 days divided into 12 months with a leap day to be added to February every four years. The Julian year is, therefore, on average 365.25 days long.

However, the true length of the tropical year is 365.2422 days. Hence, the Julian calendar was too long by $11^m\ 14^s$. The result was that the Sun arrived at the vernal equinox earlier and earlier each successive year. By the sixteenth century, the date of the vernal equinox had moved to March 11. So in 1582, Pope Gregory XIII selected a committee to study the scientific data and implications involved in reforming the calendar. The committee included Father Christopher Clavius (March 25, 1538 – February 12,1612), a Jesuit mathematician and astronomer from the Roman College, who expounded and explained the reform. (In his last years, Clavius was probably the most respected astronomer in Europe and his textbooks were used for astronomical education for over fifty years in Europe and even in more remote lands. Clavius was also one of the first mathematicians to introduce the decimal point). The matter of reforming the calendar apparently sparked an interest in the Papacy for astronomical research and eventually led to the founding of the Vatican Observatory.

The reform to the calendar that Clavius developed was essentially to declare that only century-end years divisible by 400 would be leap years. Other century-end years would not be leap years. For example, 1600 would be a leap year, but not 1700, 1800, or 1900. The year 2000 was a leap year, but 2100 will not be. In effect, this scheme reduced the average length of the calendar year to 365.2425 days and would become known as the Gregorian Calendar. To institute the new calendar, other adjustments to the current year at that time were necessary. So, by Papal decree, October 4, 1582 was followed by October 15, 1582, thereby dropping 11 days from that year. This had the effect of moving the date of the vernal equinox to March 21, which is when it was occurring at the time of the Council of Nicea in the 325 AD. This council was convened by the Roman Emperor Constantine to establish the main tenants of Christianity, which the Emperor declared to be the official religion of the Empire.

Protestant countries such as England and its American colonies did not immediately adopt the Gregorian calendar and kept using the Julian calendar. Eventually, Parliament adopted the Gregorian reform in 1752. This was accomplished by having September 2, 1752 be followed by September 14, 1752, thereby bringing the first day of spring to coincide with the calendar of most other countries that were already using the Gregorian calendar. It was also decided to move January and February to the beginning of the year rather than have these months at the end of the year. This was accomplished by declaring that, what would have been January 1, 1752, became instead January 1, 1753. Therefore, in English history, 1752 had no January or February and was only ten months long.

The dropping of 12 days from the year 1752 in England actually sparked riots in England. People thought that they were deprived of almost two weeks of pay. Furthermore, unscrupulous landlords were charging rent for those 12 days.

Even today the Orthodox Church (with the exception of Romania, Estonia and Finland) still use the Julian calendar for calculating the dates of moveable feasts. Some Orthodox churches have adopted the Revised Julian calendar for the observance of fixed feasts, while other Orthodox churches retain the Julian calendar for all purposes. The Julian calendar is still used by the Berber people of North Africa. Russia did not switch to the Gregorian calendar until after the revolution in 1918.

Assignment 3-C.1:

Print this page and submit for grading. For latitude 40° N., find the NCP and SCP, draw the axis of rotation, the celestial equator, and the diurnal circle of the Sun on the days of the solstices and the equinoxes. Label everything you draw. See the instructions for drawing diurnal circles in the Appendices.