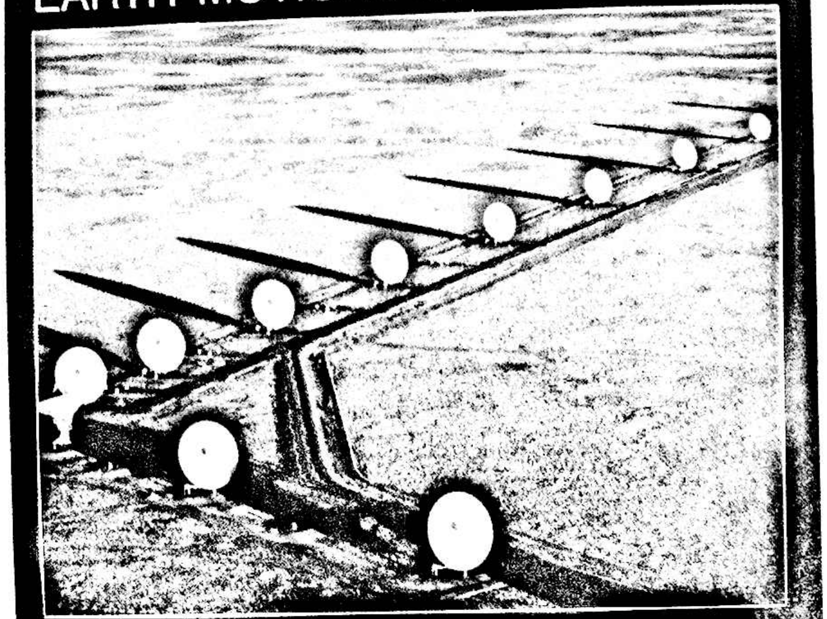
TOPIC IV
EARTH MOTIONS



With radio telescopes, such as the Very Large Array in New Mexico, we can "see" much further into space than with optical telescopes.

CHAPTER 6
Motions in the Sky

In this chapter we will examine some of the observations with which we can form a model of the earth's environment–the space around us, the other objects in it, and the way those objects move. To an observer on the earth, the earth appears to be stationary, while the sun, moon, stars, and planets revolve about it. This is the model that nearly all scientists and other educated people accepted for thousands of years. Then, starting about 400 years ago, this model was gradually replaced by another. Today, it is that other model, with the earth and the other planets revolving about the sun, that we all accept as established "fact."

Why was that earlier model satisfactory for such a long time, and why was it finally given up and replaced by almost its opposite? Let us look at the evidence, think it through, and draw our own conclusions.

You will know something about motions in the sky if you can:

1. Make observations of the apparent motions of the stars and describe a star's "life-cycle" in terms of the H-R diagram.
2. Describe the apparent motions of the sun with respect to the stars observed during the course of 1 year, and the pattern of change in its daily motion across the sky.
3. Describe the apparent motion of the moon with respect to the stars and the cycle of the moon's phases.
4. State the relationship between units of time and celestial observations.

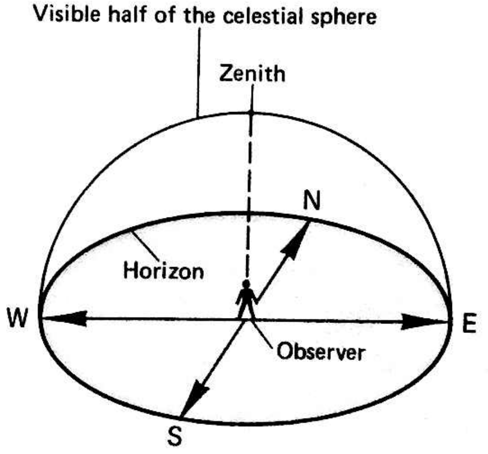
CELESTIAL OBSERVATIONS

Making Celestial Observations. One of the objectives of this chapter is to enable you to *collect* data from the sky. This objective cannot be accomplished unless you go outside and do some of your own stargazing. No matter how skillfully we may describe a certain observation, it can never be as vivid and meaningful as a firsthand experience. We feel very strongly that the study of earth science should be a series of firsthand experiences. So, we encourage you to be curious enough to gain the experiences for yourself.

When you do go stargazing, you may make some unexpected discoveries. Most people enjoy the sight of the stars on a clear night. But very few know that the stars change position during the night, or that the stars they can see in July are quite different from those they can see in January. Yet it can be very satisfying to know the names of the brighter stars, to know where and when to look for them, and to recognize them as old, dependable friends.

The Celestial Sphere. As you look at the nighttime sky, it appears like a large dome, or hemisphere, over your head. The highest point is directly overhead. This point is called the *zenith*. The edge, or rim, of the hemisphere is the *horizon*. These are labelled in Figure 6-1. Note that your position is at the center of the diagram. This model of the sky is called the *celestial sphere*. We see only the half of it that is above the horizon at any one time. The stars, moon, and planets seem to be located on the sphere, all at the same distance from the earth. The actual distances of

Figure 6-1. The celestial sphere. At any given time, an observer on the earth can see half of the celestial sphere.



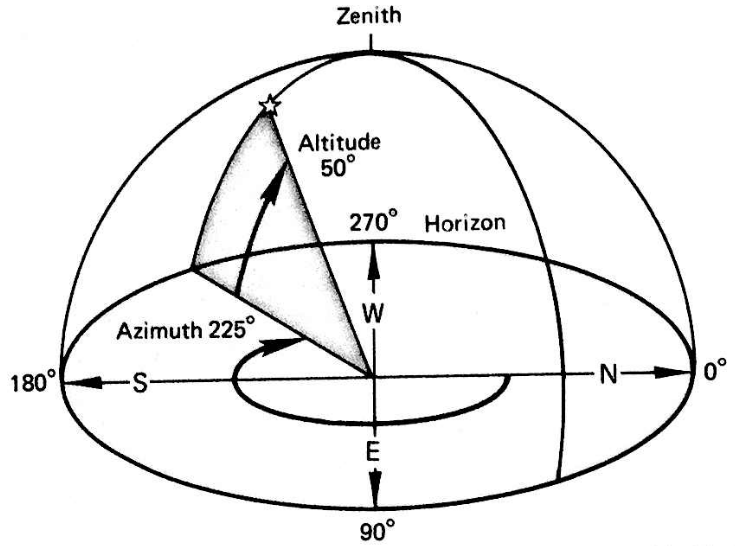


Figure 6-2. Altitude and azimuth. To describe the location of a celestial object you need two measurements, or coordinates. In the system shown, these are the altitude—the angular distance of the object above the horizon—and the azimuth—the angular distance around the horizon from some reference point (in this case, due north).

these objects from earth are so great that our depth perception cannot tell us which ones are farther and which ones are closer.

However, we can describe where a celestial object appears to be at a given moment. To do this, we measure two angular distances. One of the measurements is the distance above the horizon *(vertical angle)*, called *altitude;* the other is the distance around the horizon from some reference point *(horizontal angle)*, called *azimuth*. These measurements can be made using the techniques shown in Figure 6-2.

Using Star Maps. Figure 6-4 shows the night sky as it appears to an observer at a latitude of 42° north. To use the map, hold it over your head with the arrow marked "N" pointing north. Match this with the real stars.

The center of the map is the zenith—the point directly overhead. Stars near the edge of the map are close to the horizon, in the direction indicated along the outside of the diagram. For example, the two brightest stars in the constellation Orion (Rigel and Betelgeuse) are just over the horizon and directly to the east. A line drawn from the zenith to the horizon passes near all the stars you see as you face that point on the horizon and let your gaze travel up to the zenith. Thus, if you face northwest, you will find the star Vega (the second brightest we see in our latitudes) about one-quarter of the distance up from the horizon to the zenith. With a little practice you can learn which part of the sky corresponds to each region of the map.

Notice that the east and west points on the horizon are shifted toward the north in this diagram, and the horizon is an ellipse rather than a circle. This has been done so that the paths of the stars on the map become circles around Polaris. As we will soon see, these are the paths the stars seem to follow during the night.

To find north you can use a magnetic compass. But it is more convenient to learn to find Polaris, the Pole Star, by means of the "pointer" stars in the bowl of the Big Dipper. Figure 6-3 shows how to do this. Face the Pole Star and you will be facing due north.

Star Paths During the Night. Figure 6-4 is a star map for the sky at about 8 P.M. (Standard Time) in the middle of November. The brightest stars and the best-known constellations for this season of the year are labeled on the map. On a clear night go to an unobstructed area away from bright lights, and you should be able to find them all.

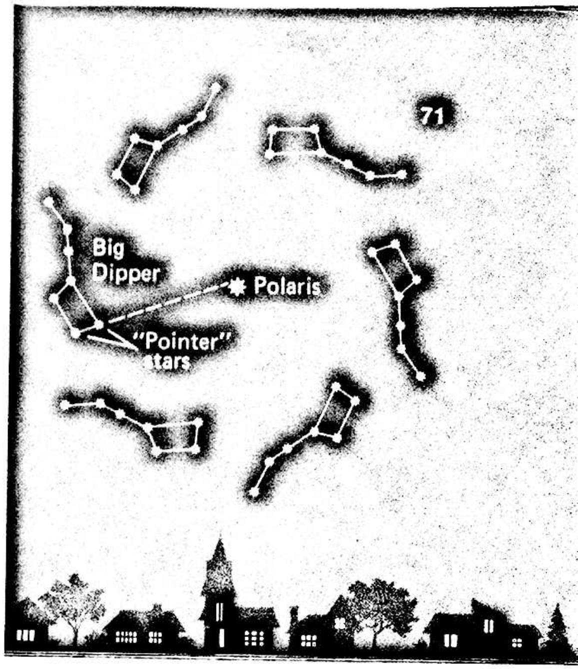
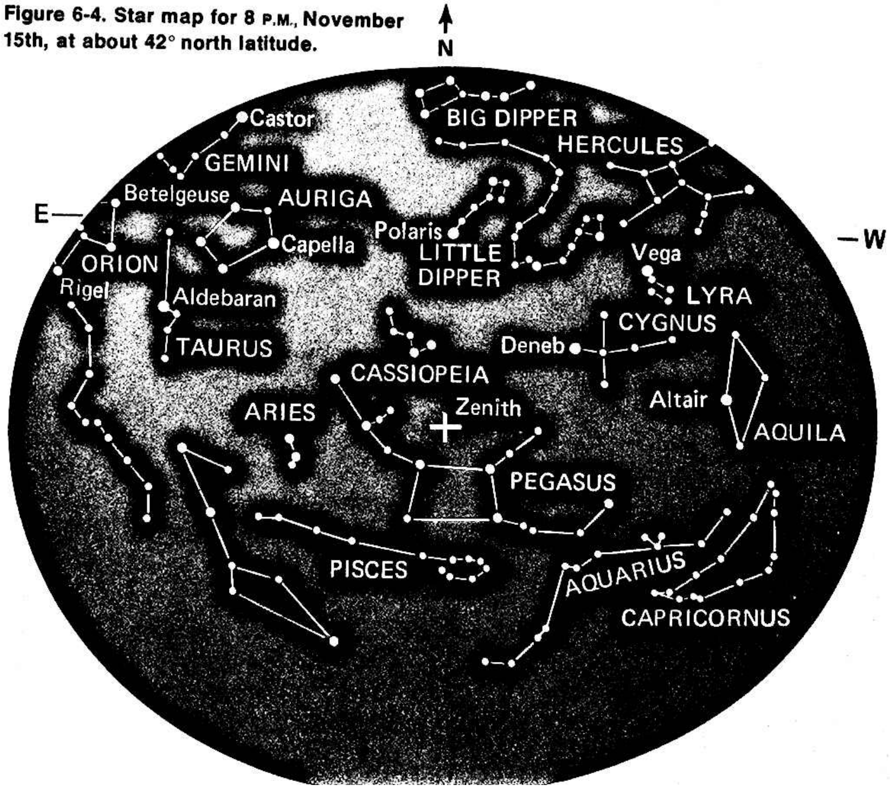


Figure 6-3. Using the "pointer stars" of the Big Dipper to find Polaris. The position of the Big Dipper depends on the time of night and the season of the year.

Figure 6-4. Star map for 8 P.M., November 15th, at about 42° north latitude.



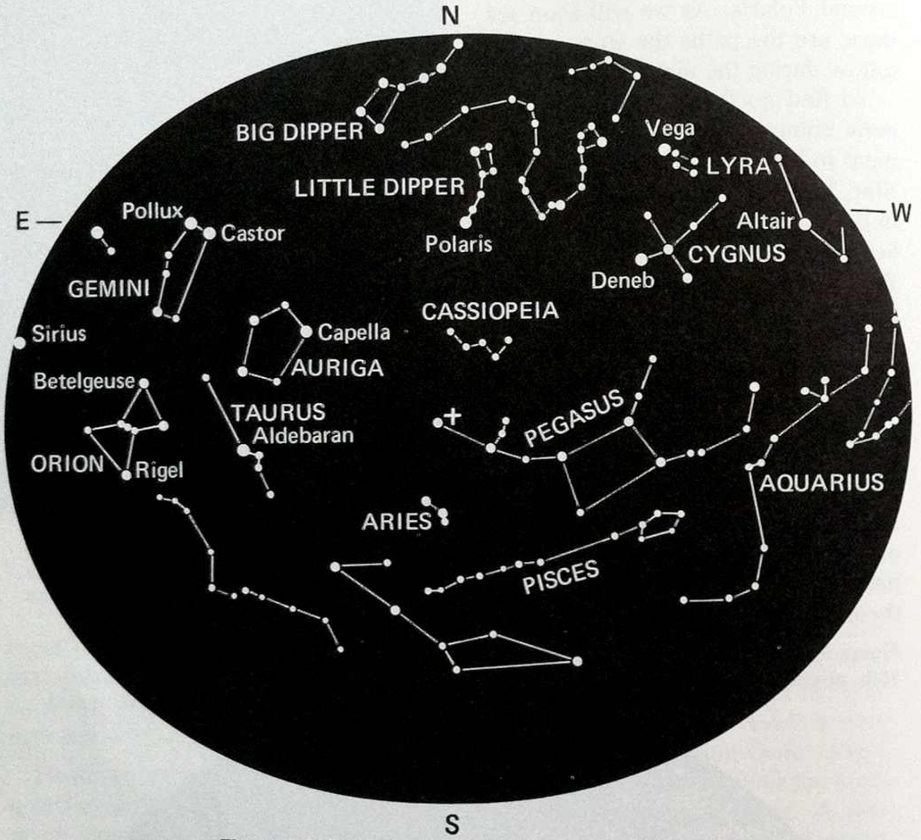


Figure 6-5. Star map for 10 P.M., November 15th.

Figure 6-5 is a map for the same date, but 2 hours later—about 10 P.M. Compare the two diagrams carefully to see what changes you can find.

Notice that some stars near the eastern horizon (for example, the constellation Orion) have risen above the horizon. Stars that had been in the western part of the sky have set (constellation Hercules). Most of the stars have simply moved to new locations. One star, however, the Pole Star, has not moved.

If you observed the stars for an entire night, you would see many stars rise in the east, while others were setting in the west. All the stars would appear to move across the sky, although the Pole Star would move so little as to appear practically stationary. The actual paths of these motions could be recorded on photographic film by means of a time exposure with a camera. In a time exposure, the camera is in a fixed position and the shutter is open. Anything that moves during the period of the exposure will produce a blurred image across the film. This image will trace the apparent path of the object. In the case of a time exposure of stars, the star paths are thin lines, called *star trails*.

If the camera is facing the Pole Star, the star trails are quite interesting. They form parts of circles around the Pole Star as a center. We see such a time exposure photo in Figure 6-6. An exposure made in any other direction is less revealing. Figure 6-7 *A*, *B*, and *C* show time exposures of the stars taken toward the east, west, and south (but not in that order). Can you match each picture with its compass direction? You are a first-rate observer if you matched *A* with west, *B* with south, and *C* with east.

The star trails in the three photos of Figure 6-7, if examined carefully, will be seen to be curved. However, it is not easy to see whether they have any relation to each other or to the Pole Star. The situation will be clearer if we take a look at star trails at other latitudes.

Observing Stars at Other Latitudes. You may remember from Chapter 4 (page 56) that the altitude of the Pole Star depends upon your latitude. If you are at latitude 90°N (that is, at the North Pole), the Pole Star is directly overhead. At the North Pole, not only do the stars near the Pole Star make circular trails, but *all* the stars do so. All the star trails for an observer at the North Pole are full circles in the sky, and they are all parallel to the horizon (see Figure 6-8).

At the equator, or latitude 0°, the Pole Star is on the horizon, due north. For an observer on the equator, all the star trails are half-circles, and they all meet the horizon at right angles (see Figure 6-9).

We can now understand the star trails in intermediate latitudes, such as ours. These trails are also circular. However, the circles are inclined to

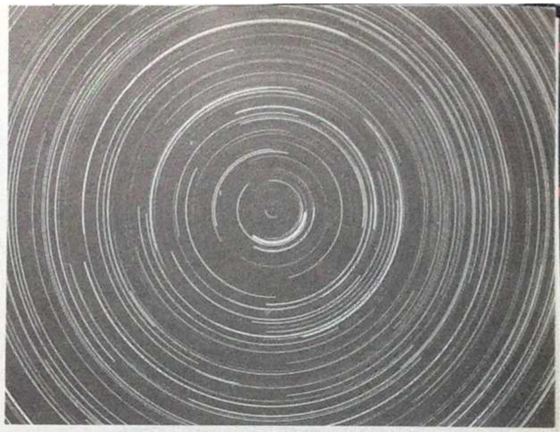
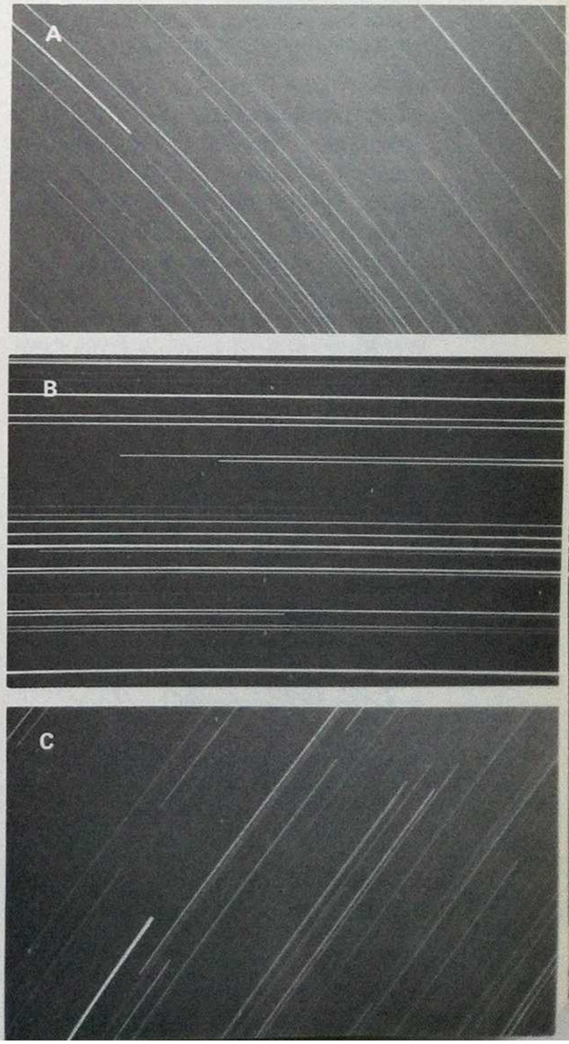


Figure 6-6. Star trails around Polaris.

Figure 6-7. Star trails at eastern, western, and southern horizons (not in that order).



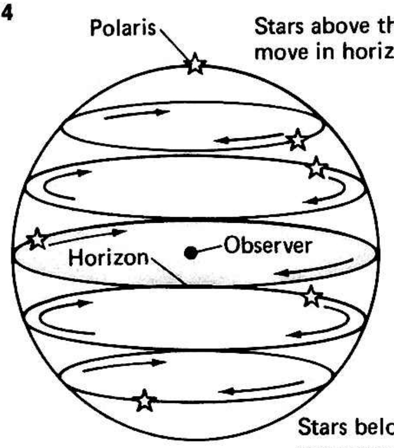


Figure 6-8. Apparent motion of the stars when observed at the North Pole.

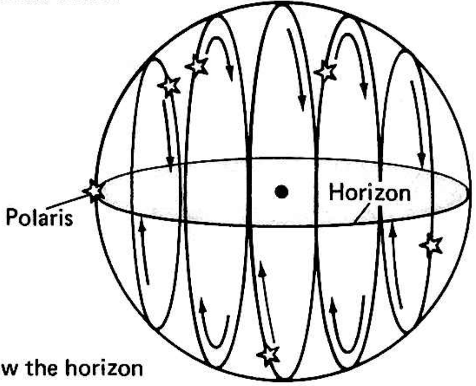
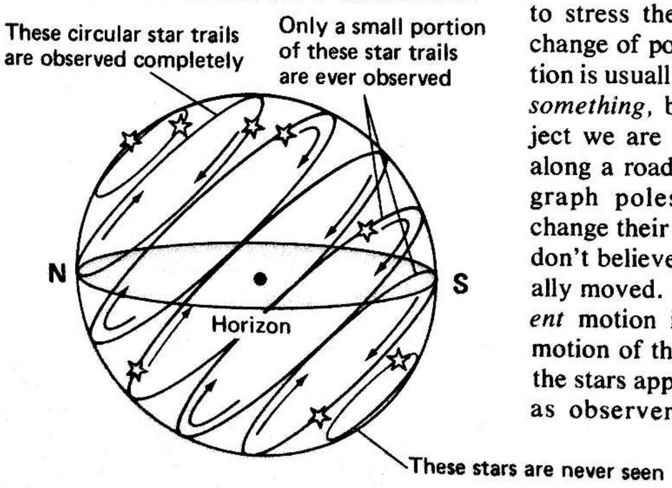


Figure 6-9. Apparent motion of the stars when observed at the equator.

the horizon. Stars near the Pole Star make small circular trails that are completely visible. The trails of other stars meet the horizon at an oblique angle. In the case of stars in the southern sky, only a small part of the circle is visible above the horizon (see Figure 6-10).

Apparent Daily Motion of the Stars. We have now discovered that the stars appear to move in circles. Furthermore, if you examine Figures 6-4 and 6-5, which show the stars at two different times, you will notice something else of importance. Although all the stars moved, they did not change their positions relative to each other. The stars of the Big Dipper are in the same position relative to each other, and the Big Dipper as a whole is in the same position relative to other stars and constellations. The apparent motion of the stars is not only circular, but also uniform.

Figure 6-10. Apparent motion of the stars when observed at about 45° north latitude.



You may have noticed our frequent use of the word "appears" or "apparent" in connection with the observed motion of the stars. We have done this to stress the fact that we *observe* a change of position. A change of position is usually caused by the motion of *something,* but it need not be the object we are observing. As you drive along a road, the trees, houses, telegraph poles, and hills appear to change their positions. However, you don't believe these objects have actually moved. You infer that the *apparent* motion is caused by the "real" motion of the car you are in. We see the stars appear to move relative to us as observers. Again we infer that *something* moved. Was it the stars? Was it ourselves? Or was it both? These questions are not easy to answer.

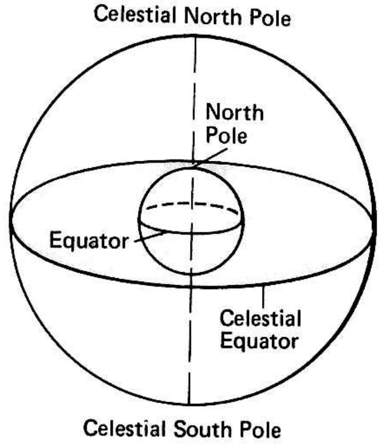


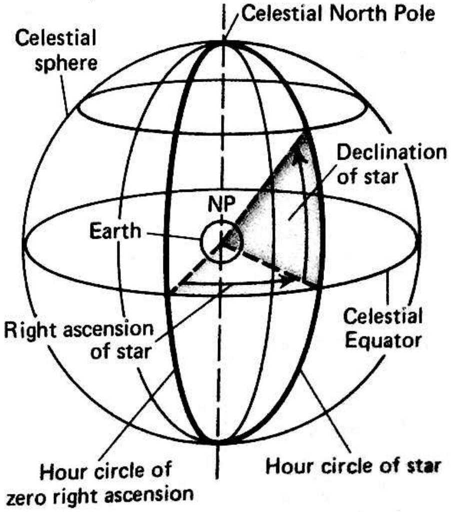
Figure 6-11. Celestial equator and poles. The celestial equator is a projection of the earth's equator, and the celestial poles are projections of the earth's North and South Poles.

Apparent Motion of the Celestial Sphere. We can now describe the apparent daily motion of the stars in a simple way. We imagine that the celestial sphere is the expansion of the earth's surface outward to some great distance. This sphere has a *celestial equator* that is a projection of the earth's equator, and two *celestial poles* that are projections of the earth's poles, as shown in Figure 6-11. Each star has a fixed location on the celestial sphere. If we imagine the sphere rotating around an axis through the poles of the earth, each star will be carried along its star trail as observed from the earth. If we time the apparent motion of the celestial sphere, we find that its apparent rate of rotation is once a day; that is, 360° in 24 hours, or 15° per hour.

Locations on the Celestial Sphere. Figure 6-12 shows how the positions of the stars on the celestial sphere can be described. Each star trail is a circle parallel to the celestial equator. It is exactly equivalent to a parallel of latitude on the earth's surface. Its angular distance north or south of the celestial equator can be measured in degrees. This angular distance is called *declination;* instead of describing it as "north" or "south," we use a + sign for declinations to the north and a − sign for declinations to the south.

We can also imagine lines on the celestial sphere similar to meridians on the earth. These are circles passing through the celestial poles and crossing the celestial equator at right angles to it. To measure "longitude" on the celestial sphere, we need a "merid-

Figure 6-12. Locating stars on the celestial sphere. Stars are located on the celestial sphere by two coordinates—the angular distance above or below the celestial equator (called declination) and the angular distance from the reference meridian (called right ascension).



ian" to serve as zero. Note that a "meridian" through any star could have been chosen for this purpose. But astronomers have picked another reference point. It is determined by the sun's apparent motion among the stars, and will be explained later.

A different term is used for the measurement of this point. It is called *right ascension* (R.A.). Instead of expressing it in degrees, it is customary to express it in hours, minutes, and seconds of time. However, since 24 hours of rotation is equal to 360°, each hour of right ascension is equal to 15° of angular distance. The meridian through any star is called its *hour circle.*

Earlier, we suggested that you observe the sky for an entire night to become aware of the apparent westward motion of the stars. If you were to continue this observing during an entire year, you would notice another change.

While the stars seem to travel daily on circular paths from east to west, or counterclockwise as we look at the Pole Star, each night they appear to be slightly farther toward the *west* than they were the night before. In other words, they are moving slightly faster than one revolution per day. After a period of one year, the stars are back where they started, the cycle completed. This apparent westward shifting of the stars in addition to their daily motion is called *annual,* or yearly, motion.

Our Local Star—the Sun. If you tried to observe the motion of the stars, as suggested earlier, you probably wondered what you would find if you could see them better. It just so happens that you have one you can observe very easily—the sun. All the stars you can see (and others visible only through telescopes) are similar to our sun.

First of all, stars produce their energy by *nuclear fusion.* Our sun converts 600 million metric tons of hydrogen into 596 million metric tons of helium every second. The 4 million metric ton difference is matter that is converted into energy. Other stars undergo different nuclear reactions, but all convert matter into energy by nuclear fusion.

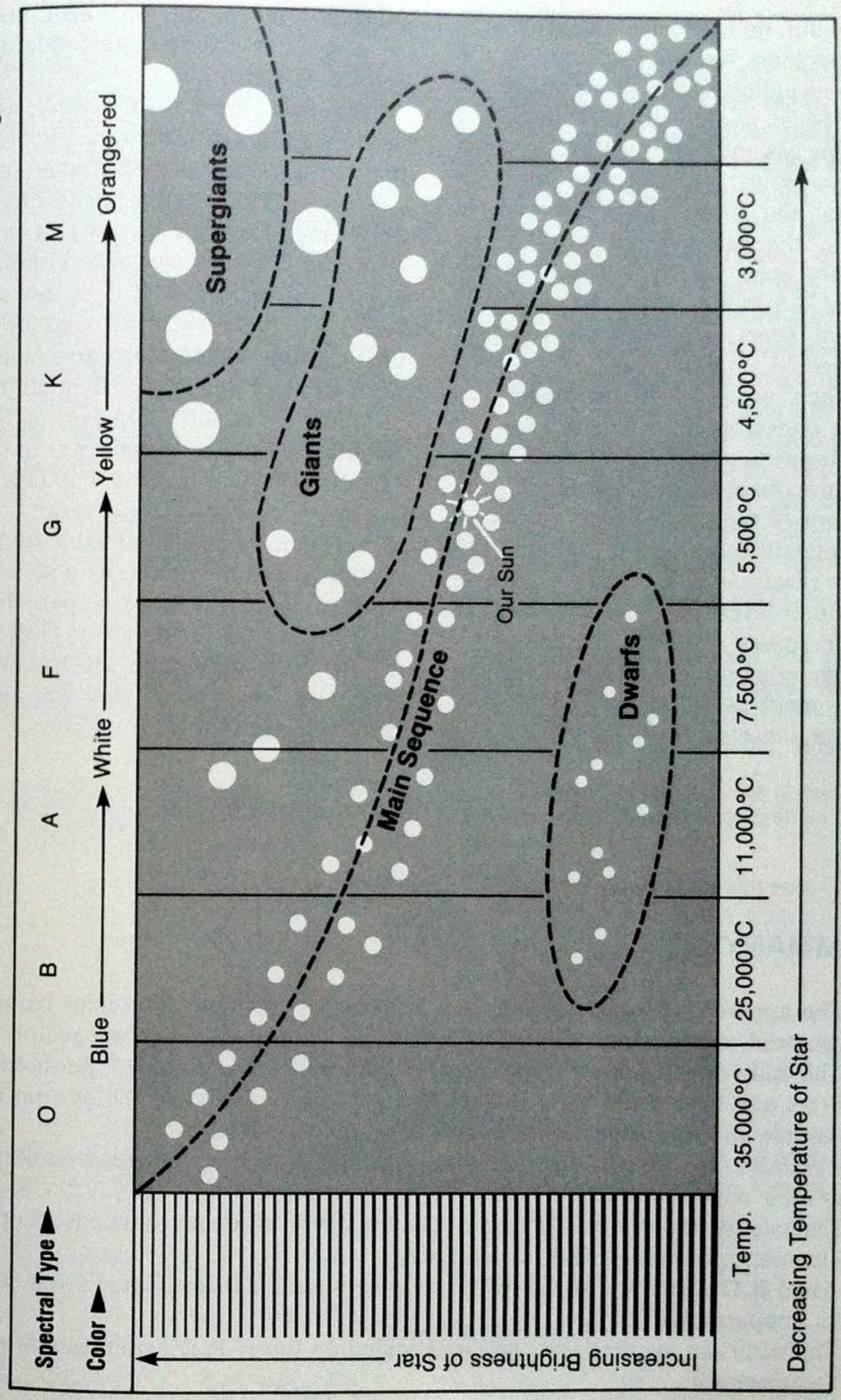
In 1910, two astronomers independently developed a system for classifying stars by their temperature and brightness. The H-R Diagram was named in honor of the Danish astronomer Ejnar Hertzsprung and the American astronomer Henry Norris Russell. The key to this classification is the spectral type of the star, primarily determined by analyzing its light through a spectroscope. You will learn more about the electromagnetic spectrum in Chapter 8.

Figure 6-13 shows the H-R Diagram, with the sun marked where its temperature and brightness locates it on the graph. You can see that the sun is a rather ordinary star, not very hot and not very bright. It belongs in the band labeled Main Sequence stars. Other stars are brighter than the Main Sequence stars, and are classed as Giants or Supergiants. Still others are hotter, but dimmer. These are grouped as the Dwarf stars. Astronomers use the H-R Diagram to explain the life sequence of stars.

According to the diagram, what does the future hold for our own star, the sun? If it is converting its major element, hydrogen, into helium at such a tremendous rate, will it soon

Figure 6-13.

Hertzsprung-Russell Diagram



fade out of existence? Here is how astronomers see the life story of the sun, including its remaining years.

It began as a protostar, with gravity pulling gas and dust together. At some critical point, the early star began to warm and glow. After millions of years, the sun became a Main Sequence star, where it has been for about 4.5 billion years. In another 5 billion years, it will make another change.

When much of its hydrogen has been converted into helium, the sun will begin to grow bigger, redder, and brighter, becoming a Red Giant. The interior of the sun will then be almost completely composed of helium. Nuclear reactions will begin to occur in the outer layers of the sun. Because of the increased reactions, the amount of energy released will increase, perhaps by as much as 100 times. The intensity of the sunshine on Saturn will be as great as it is presently on Earth, and, of course, it will be tremendously greater on Earth.

After that, the sun will shrink, and become bluer and dimmer. It may then go through a variable stage, expanding and contracting many times; or it might become a *nova,* a star whose outer layers have blown off like a giant firecracker. If it does not destroy itself, however, it will continue to shrink, eventually turning into a fading white dwarf. From the Earth in this far distant time, a very cold person will see the sun only as a bright star in the sky. Its light will be only 1/10,000 as bright as it is now. As a result, the planets will be invisible to this future earthling, and the moon, with so little light to reflect, will be a pale and ghostly object in the dark sky. However, before you become too worried, remember that all of this will take place billions of years from now.

SUMMARY

1. The apparent daily motion of stars is from east to west in circular paths, centered on an extension of the earth's axis, and parallel to the equator.
2. The daily rate of apparent motion of stars is uniform at about 15° per hour.
3. Stars can be located by a system of coordinates similar to the system of latitude and longitude for locating places on the earth.
4. The stars also have an apparent annual motion from east to west in addition to their daily motion.
5. The energy of a star is a product of nuclear fusion reactions that convert one element into another and release energy.
6. An H-R Diagram shows the relationship between the brightness of a star and its temperature.
7. The sun is an average star, and is classified on the H-R Diagram as a Main Sequence star.

MOTIONS OF THE SUN

Motion of the Sun Among the Stars. What is the apparent path of the sun among the stars? Since we cannot see the stars when the sun is in the sky, we cannot directly observe the position of the sun on the celestial sphere. However, we can figure out its position indirectly by making a series of observations over a period of time.

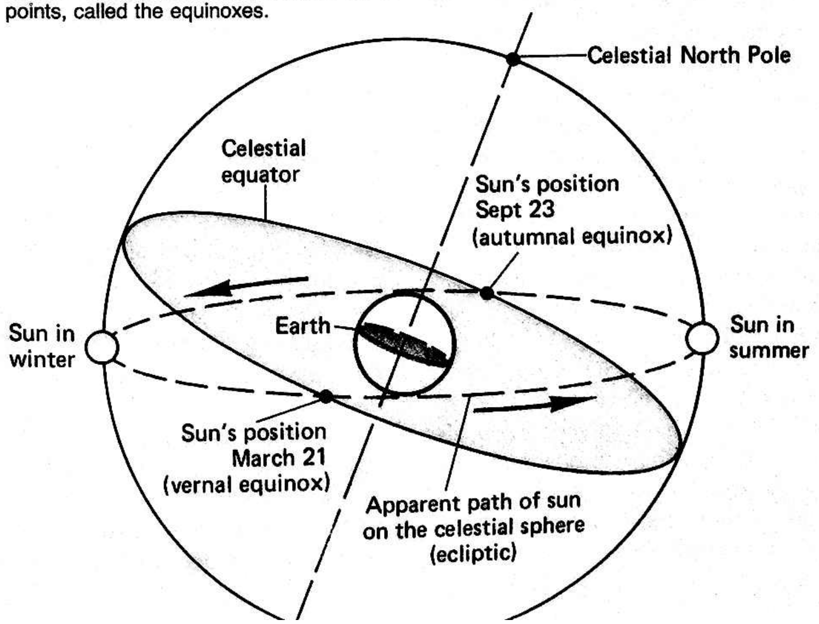
In the early morning of any day, shortly before sunrise, we can see the stars that are somewhat to the west of the sun. These are the stars that have just risen in the east. Then, as the sky brightens, the stars fade from view. Stars very close to the sun's position rise too late to be visible.

In the early evening, shortly after sunset, we see the stars that are somewhat to the east of the sun. These are the stars that are just about to set in the west. Again, we have missed a few stars very close to the sun that set before the sky became dark enough for us to see them. We have missed seeing a few stars on either side of the sun, but we now know that the sun was among them.

As the days pass, the stars gradually shift westward with respect to the sun. Or looked at another way, the sun gradually shifts eastward with respect to the stars. After a few weeks, the sun is among a different group of stars. Now, in the early morning we can see the stars that we missed during the earlier observations. The entire group where the sun had been now rises before the sun. We can therefore figure out where the sun must have been among them at that time.

In this way, we can plot the sun's apparent path among the stars. When we do this, we obtain a circle called the *ecliptic* (see Figure 6-14). It takes

Figure 6-14. The ecliptic. It takes the sun one year to make a complete circuit of the ecliptic—its apparent path among the stars. This path crosses the celestial equator at two points, called the equinoxes.



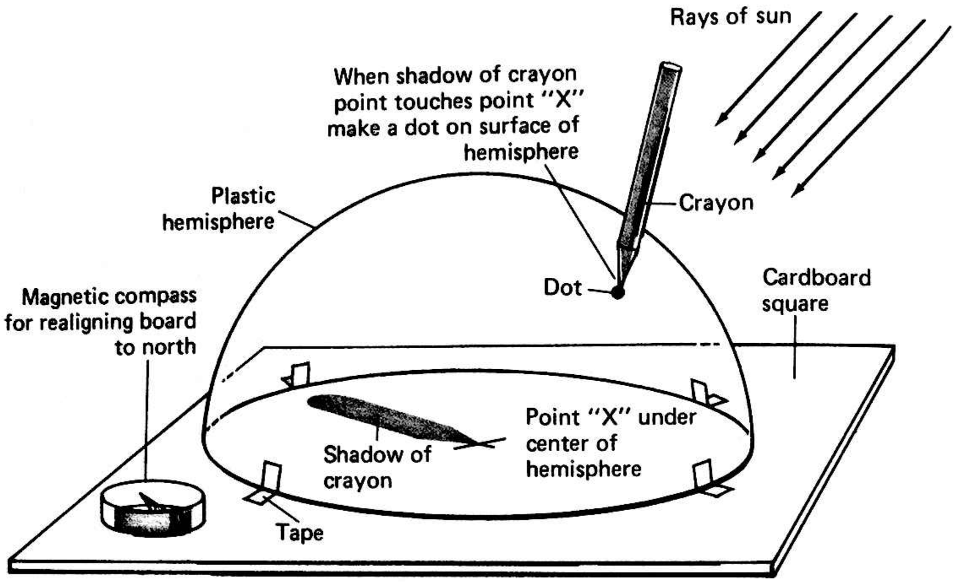


Figure 6-15. Observing the sun with a model of the celestial sphere.

the sun one year to make one complete circuit of the ecliptic. The center of the ecliptic is the center of the earth. The plane of the ecliptic is inclined at an angle of 23½° to the plane of the celestial equator. Therefore, the ecliptic (the path of the sun among the stars) crosses the celestial equator at two points. In other words, the sun is on the celestial equator twice during the year.

One of these dates is March 21, a date called the *vernal equinox*. The point where the ecliptic crosses the celestial equator at the vernal equinox has been chosen as the zero point for right ascension. The hour circle through this point has a right ascension of zero. You can see that at the vernal equinox the sun has a declination of zero (it is on the celestial equator), and a right ascension of zero (it is on the zero hour circle).

Observing the Sun During the Day. Up to this point we have been considering observations made mainly at night. Now let's make some daytime observations. Let's look at the brightest object in the sky—the sun. We don't really mean this last statement the way it sounds. *Never look directly at the sun!* The intensity of the sunlight is so great that you risk permanent damage to your eyes even glancing directly toward a bright sun. Telescopes or binoculars increase the chance of injury. You may have seen the heating effect of sunlight brought to a focus by a lens or reflector. These devices can be used to *cook* food or *melt* metals!

There are several ways you can observe the sun, however. Figure 6-15 shows one method of observing the sun's position and recording it on a model of the celestial sphere. If the materials are available, this method works very well.

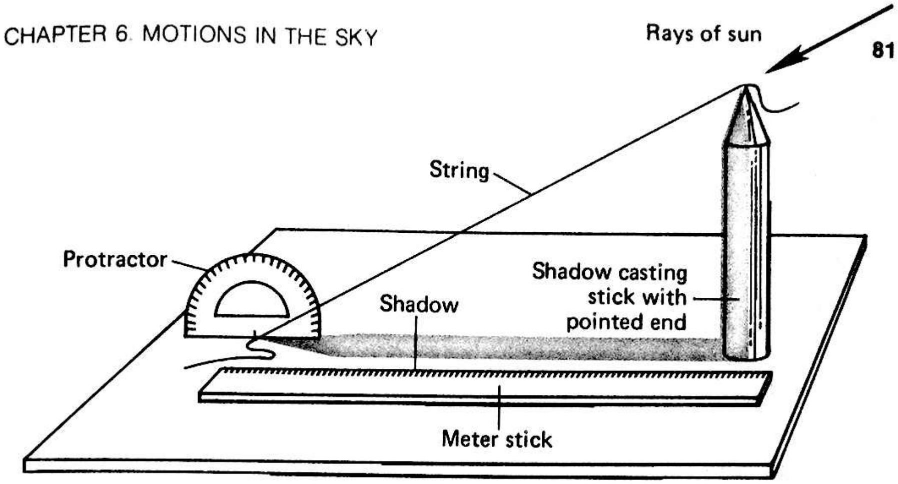


Figure 6-16. Observing the sun by measuring shadows.

Figure 6-16 shows another simple method. You can mark the end of the shadow at various times. Later you can measure angles, if you need this information. Frequently, the pattern produced by the positions of the shadow points is all the information you need.

Making observations of the sun can be just as fascinating as stargazing. The pastime can continue year-round. In fact, some of the observations that you might want to make *should* be done year-round.

Apparent Size of the Sun. One interesting observation of the sun that can be made with a very simple apparatus is the change in its apparent diameter. This can be done by using a pinhole in a card to project an image of the sun on a screen, as shown in Figure 6-17. If this is done at different times of the year, the diameter of the image is observed to vary in a cyclic manner. The change is not large—about 3% from maximum to minimum—but it is not difficult to measure. This observation could mean that the actual size of the sun changes in the course of a year. Or it could mean that the sun remains the same size, but its distance from the earth changes. The second hypothesis seems the more likely explanation.

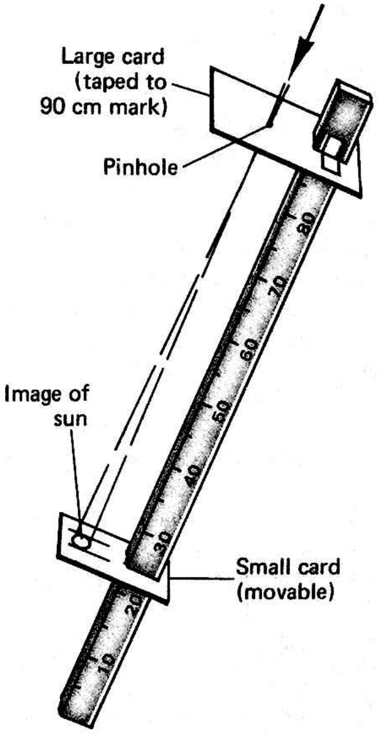


Figure 6-17. Observing the apparent change in the size of the sun.

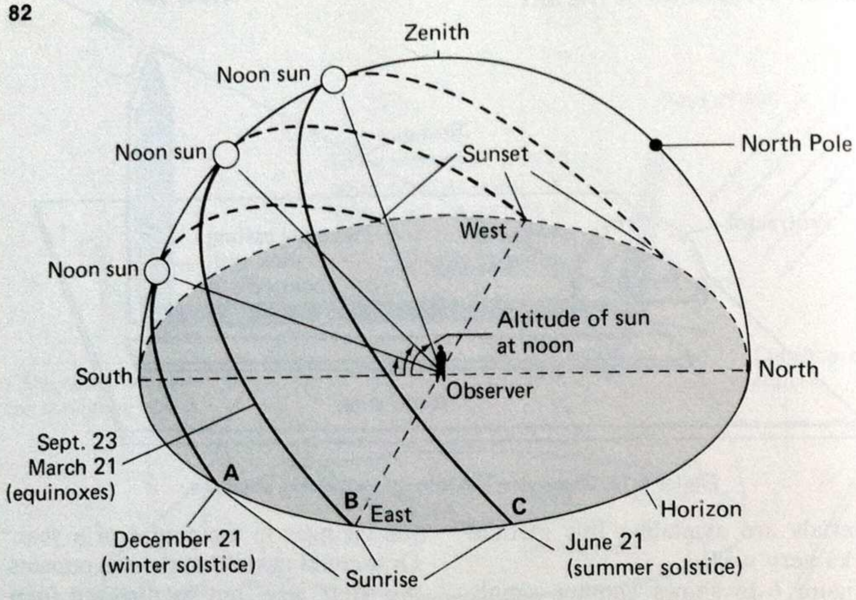


Figure 6-18. Sun's daily path at 42° north latitude for three different seasons of the year.

Motion of the Sun During the Day. Even the most casual observer realizes that the sun rises in the morning and sets at night. But if you ask someone where on the horizon does the sun rise and where does it set, the answers usually become much less definite. If you ask where the sun is in the sky at noon, many people will tell you that it is overhead. If you ask, "Directly overhead?," most people will think so, or again their answers are unsure. The first observations that we need are ones that will help answer our questions with certainty.

Figure 6-18 shows the results of observing the sun's position in the course of one day at latitude 42°N. If you observe the sun's path on September 23, the path labeled *B* is traced. The positions of sunrise, noon, and sunset are labeled. The sun's altitude at noon on September 23 is 48°.

If you observe the sun's path again about December 21, path *A* is traced. Sunrise on December 21 is in the southeast, and sunset is in the southwest. At noon the sun's altitude is only 24.5°.

If you observe the sun's path about March 21, it again follows path *B*. The noon altitude is 48° again. If you observe the sun's path about June 21, path *C* is traced. Sunrise on June 21 is in the northeast, and sunset is in the northwest. At noon, the altitude of the sun is 71.5°.

We now have some definite observations relating to the questions we raised earlier in this section. And we find that the answers are not simple. Where does the sun rise and set? It depends on the time of year, or season. Where is the sun at noon? Again, it depends on the season, but it is never overhead for an observer at 42° north latitude. The closest it gets to

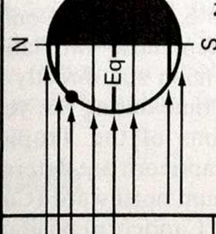
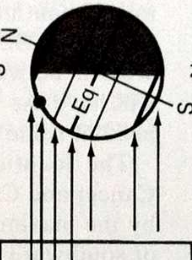
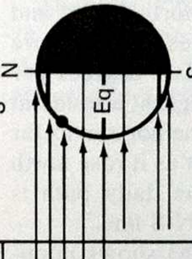
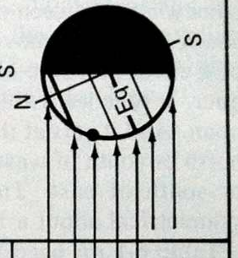
DATE	EQUATOR 0°	TROPIC OF CANCER 23.5°N	NEW YORK STATE 42°N	ARCTIC CIRCLE 66.5°N	NORTH POLE 90°N	RELATIONSHIP OF EARTH TO SUN'S RAYS	SEASONAL EVENT
Sept.23 Autumnal equinox	90°	66.5°	48°	23.5°	0°		**Fall begins** Equal day and night Sun on horizon at poles
Dec. 21 Winter solstice	66.5°	43°	24.5°	0°	Not visible		**Winter begins** Area north of Arctic Circle in constant darkness Direct rays at 23.5° S
Mar. 21 Vernal or spring equinox	90°	66.5°	48°	23.5°	0°		**Spring begins** Equal day and night Sun on horizon at poles
June 21 Summer solstice	113.5° or 66.5° above the north horizon	90°	71.5°	47°	23.5°		**Summer begins** Area north of Arctic Circle in constant light. Direct rays at 23.5°N Noon sun at equator appears in North

Table 6-1. Altitude of the sun at noon for several locations and at different times during the year.

being overhead is June 21, when it lacks 18.5° of being directly overhead.

Nevertheless, the sun's path through the sky each day does have certain regular features. The sun rises from the horizon in the morning somewhere between north of east and south of east. It moves along the arc of a circle at a rate of 15 degrees per hour. It reaches its highest altitude at noon. And it sets at the horizon as far north or south of west as it rose north or south of east. The daily path is symmetrical about a N-S line.

Table 6-1 on page 83 shows noontime altitudes for several locations on earth. Notice that the sun is directly overhead (90°) for people at the equator on September 23 and March 21. At 23.5° N (the Tropic of Cancer) the sun is overhead only on June 21. On December 21, the sun is not overhead at any of the locations in the table, but it *is* overhead at 23.5° S (the Tropic of Capricorn).

Table 6-1 includes diagrams of the sun's rays in relation to the earth's surface. They will help you visualize the effect of the changing altitude of the sun and its relation to the seasons.

The shifting of the sun's vertical rays (noontime altitude = 90°) from 23.5°N to 23.5°S means that only the area in between those two latitudes will have the noon sun directly overhead at some time during the year.

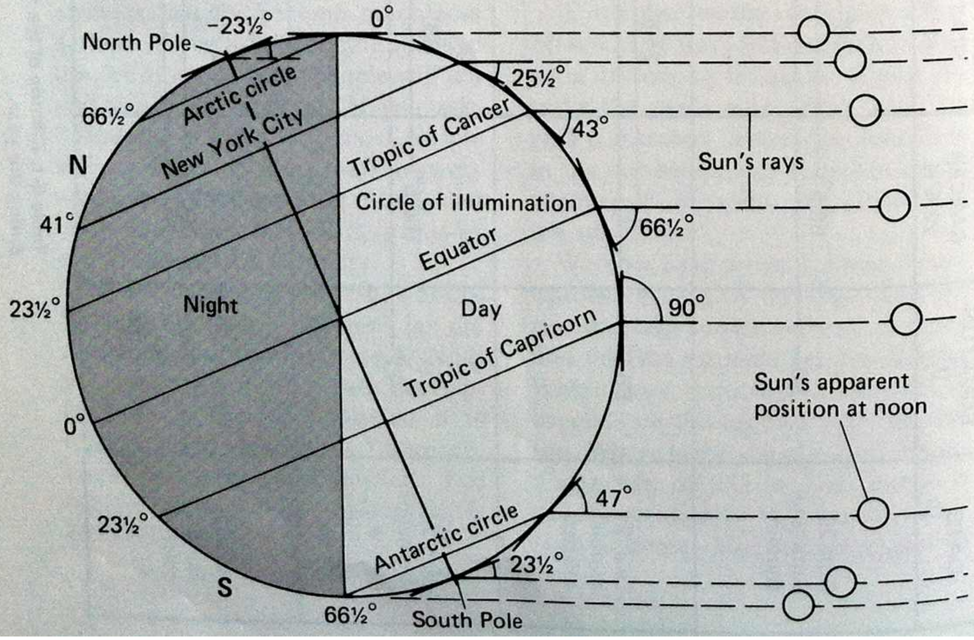
The locations of the Tropics of Cancer and Capricorn are determined by the maximum northward (Cancer) or southward (Capricorn) positions of the vertical noontime sun. The Arctic and Antarctic Circles are the maximum distances from the poles that can have 24 hours of daylight. (See Figure 6-19.)

Length of Daylight. In the summertime, we enjoy many hours of daylight, while in the winter, darkness may have fallen before we get home from school or work. These facts are to be expected from the other observations we have made.

Refer again to Figure 6-18. How do the horizon-to-horizon lengths of the arcs *A*, *B*, and *C* compare? If the sun moves along each one at the rate of 15°/hour, how will this affect the length of daylight? Path *C* is long enough to cause daylight to last for nearly 16 hours at 42°N. Path *A* provides us with daylight for only about 8 hours. If we move nearer to the North Pole, the length of path *C* will increase, because more of it will be above the horizon. Therefore, the daylight will be even longer at latitudes nearer to the North Pole.

Above 66.5°N, daylight occurs for 24 hours when the sun is traveling along path *C*. This condition is also pictured in Table 6-1 for June 21.

Figure 6-19. Altitude of the sun and number of hours of daylight.



SUMMARY

1. The sun has an apparent annual motion through the stars from west to east along a circle whose plane is inclined at an angle of 23½ degrees to the plane of the celestial equator.
2. The apparent diameter of the sun varies in a cyclic manner during the year.
3. The sun's apparent daily path through the sky is an arc.
4. The sun's apparent daily path varies with the seasons.
5. The noontime position of the sun is never directly overhead farther north than 23.5° north latitude.
6. The points of sunrise and sunset vary with the seasons.
7. The length of daylight varies with the seasons.

MOTIONS OF THE MOON

Observing the Moon. When you are stargazing, gaining the firsthand experience we mentioned earlier, you will often have an opportunity to study the moon. In fact, observing the stars is difficult when the moon is bright and high in the sky—so you may as well turn your attention to the moon at such times.

We are all so familiar with photographs of the moon from close range, and from the moon's surface itself, that studying it from the earth may seem rather a letdown. But viewing the moon through a telescope is still an enjoyable pastime, and observing the changing positions and phases of the moon is fascinating even without a telescope.

Path of the Moon Through the Stars. Most people are probably even vaguer about the apparent motions of the moon than about those of the sun. Have you given the subject much thought? Where and when does the moon rise and set? How are these events related, if at all, to its phases? When is the last time you saw a crescent moon at midnight? (If you can't recall, it is not because you have a poor memory!)

If you start recording observations of the moon on as many consecutive nights as you can, you will soon note

DAY	RIGHT ASCENSION hrs.	min.	DIFFERENCE (in minutes)	PHASE	APPARENT DIAMETER (to nearest .5 minutes)
1	13	15		🌕 Full	33.0
2	14	10	55		33.0
3	15	09	59		33.0
4	16	11	62	🌖 Old Gibbous	33.0
5	17	15	64		32.5
6	18	21	66		32.5
7	19	24	63	🌗 3rd Quarter	32.0
8	20	23	59		31.5
9	21	18	55		31.0
10	22	09	51		30.5
11	22	56	47	🌘 Old Crescent	30.5
12	23	40	44		30.0
13	0	23	43		30.0
14	1	06	43		29.5
15	1	49	43	🌑 New	29.5
16	2	34	45		29.5
17	3	21	47		29.5
18	4	11	50		29.5
19	5	02	51	🌒 New Crescent	29.5
20	5	56	54		29.5
21	6	50	54		30.0
22	7	45	55	🌓 1st Quarter	30.0
23	8	38	53		30.5
24	9	30	52		31.0
25	10	20	50		31.5
26	11	10	50	🌔 New Gibbous	32.0
27	12	00	50		32.5
28	12	51	51		33.0
29	13	44	53		33.0
30	14	42	58	🌕 Full	33.5
31	15	43	61		33.5
32	16	48	65		33.5

Table 6-2. Right ascension and phases of the moon for 32 successive days.

that the moon rises about an hour later each night. In other words, the moon moves noticeably eastward among the stars in the course of one day. This motion can be more precisely described by recording its right ascension at the same time each night. Table 6-2 shows such data for 32 successive days. To help interpret this data, the *change* in right ascension each day is also listed. We see that the moon moves steadily eastward through the stars at a rate that varies from a minimum of 43 minutes

of R.A. in one day to a maximum of 66 minutes, averaging about 50 minutes per day during this period of observation.

Time for One Complete Circuit. How many days are required for the moon to return to approximately its same position among the stars (that is, to the same R.A.)? On Day 1, the R.A. was 13 hr 15 min. On Day 28, the R.A. was 12 hr 51 min. On Day 29, it was 13 hr 44 min. So the moon was back at 13 hr 15 min at some time between Day 28 and Day 29. Since we started on Day 1, the time for one complete cycle was between 27 and 28 days in length. Closer analysis of the data leads to a value of about 27⅓ days.

Phases of the Moon. Table 6-2 also shows the changes in the appearance of the moon's face during the period of observation. As you know, these changes in appearance are called the *phases* of the moon. The period of observation started on a day when the phase of the moon was full. When the moon returned to the same place among the stars (the same R.A.) on Day 28, it was not at the same phase as it was on Day 1. The phase did not become full again until some time on Day 30.

How many days elapse between successive full phases? Using the procedure above, we subtract 1 from 30 and obtain 29 days. More precise observations produce a value of about 29½ days. Thus, the period of time between successive full phases is *longer* than the period of time for the moon to arrive back at the same R.A. *by more than two days!* Our model of celestial motions must account for this observation.

Apparent Diameter of the Moon. Since it is quite safe to look directly at the moon, there are various simple methods for observing its apparent diameter. Table 6-2 includes data on the moon's apparent diameter. It can be seen that the apparent diameter goes through a cycle of variations.

SUMMARY

1. The moon's motion is eastward through the stars at a nearly uniform rate of 50 minutes of R.A. per day.
2. The moon takes about 27⅓ days to complete its cycle of motion through the stars and return to the same R.A.
3. The moon's appearance goes through a cycle of phases that is about 2 days longer than its cycle through the stars.
4. The moon's apparent diameter varies in a cyclic manner.

TIME

The Meaning of Time. We always seem to be interested in time. Time comes into our conversations in many ways. Here are some examples: "What a *time* we had!" "What *time* is it?" "He got a hit every *time* he was at bat." "I need *time* to think."

It is hard to tell exactly what we mean by time, but it clearly has something to do with events. Time is a sys-

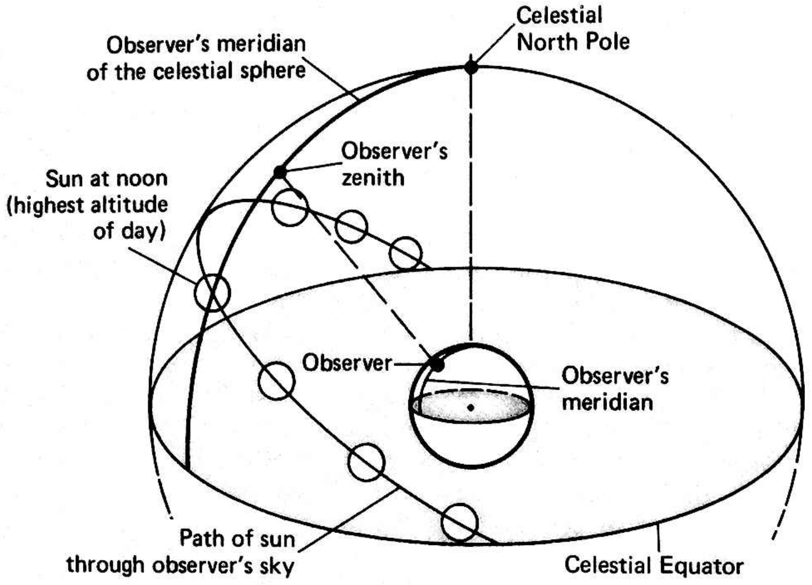


Figure 6-20. Solar noon. Solar noon at any given location occurs when the sun is centered on the meridian passing through that location. The sun reaches its highest altitude of the day at that time.

tem for arranging events in the order of their occurrence. We all talk about events that happened yesterday, or last month, and events that we expect to happen tomorrow, or next year. We are also able to state times with great precision. A class starts at 10:40 A.M. and ends at 11:20 A.M. An athlete runs 1500 meters in 3 minutes and 34.9 seconds. What do we mean by such times? How are they determined? You may say that we use clocks and calendars to measure time. But how do we set the clocks to the "right" time, and how do we know if they continue to tell the right time? In other words, what is the reference standard that we use to measure intervals of time?

Sun Time and Star Time. A circle on the celestial sphere that passes through the poles and through the point directly overhead is the observer's *meridian*. The moment the sun is centered on the meridian is called *noon*. It is also the moment the sun reaches its highest altitude of the day (see Figure 6-20). The time from one noon to the next is called a *solar day*. The clocks we use are adjusted to measure solar days. They divide the day into hours, minutes, and seconds.

We could also use the daily motion of the stars to mark off intervals of time. The time between the instant a star crosses the meridian during one night and the instant it crosses the meridian the next night is called a *sidereal day* ("sidereal" comes from a Latin word meaning "star").

As we have seen (page 76), at any given time by a solar clock, a star is a little farther along to the west on each

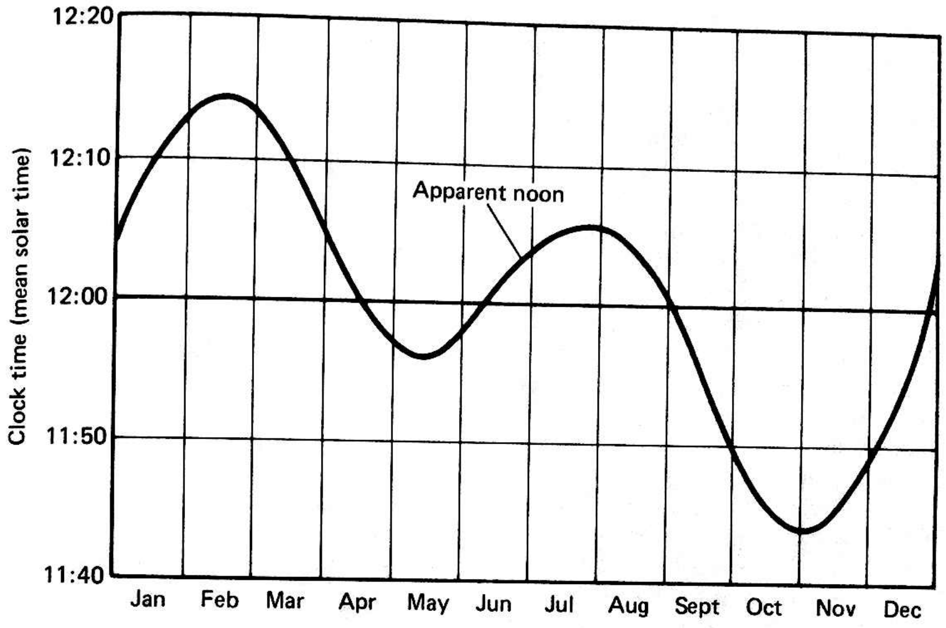


Figure 6-21. Difference between apparent solar noon and mean solar noon throughout the year.

successive night. If a star crosses the meridian at 8:00 P.M. one night, it will be past the meridian by 8:00 P.M. the next night. In other words, it crosses the meridian before 8:00 P.M. the second time. Thus we see that a sidereal day (from meridian to meridian for a star) is shorter than a solar day (from meridian to meridian for the sun). The actual difference is about 4 minutes of time.

Average (Mean) Solar Day. We have said that our clocks are adjusted to match the length of a solar day. However, we find that no clock can be made to keep exactly in step with the sun every day. Some days the clock seems to run a little fast; it reads 12:00 noon before the sun gets to the meridian. Other days it runs slow. The sun crosses the meridian before 12:00 noon. All clocks seem to have the same "error" on the same days. We therefore infer that it is not the clocks that are wrong, but the sun. That is, the apparent solar day varies in length. However, the variation follows a definite pattern through the year. It is possible to fix our clocks to measure an *average* solar day, so that the variations between clock time and solar time will cancel out over a year. The length of day that does this is called a *mean solar day*.

The variation between apparent solar time and mean solar time can be observed by noting the time at which the sun reaches its highest altitude (apparent noon) each day for a year. Figure 6-21 is a graph of the results of such a series of observations. We see that apparent noon (or "high noon") occurs at exactly 12:00 noon by the clock only four times during the year—about April 15, June 11, September 2, and December 24. At all other times, apparent noon is either earlier or later than noon by the clock. In February, apparent noon occurs almost 15 minutes late. At the end of October, apparent noon is more than 15 minutes early. However, the changes from one day to the next are small. Furthermore, the graph is a smooth curve that comes back to its starting point at the end of the year and repeats itself year after year. This means that our clocks are measuring the correct *mean* solar time.

The sidereal day does not fluctuate in this way during the year. Each sidereal day is exactly the same in length. However, it would be inconvenient to have our clocks keep sidereal time. Solar noon would occur at a different time by the clock each day. Any particular clock time, say 9:00 A.M., would occur in the morning at one season of the year, but it would be in the middle of the night at some other season. All things considered, mean solar time works best for everyday affairs.

The Year. Figure 6-21 can also help us understand what is meant by one year. The curve in this graph represents a repeating cycle. The time it takes for the sun to go through this cycle once is called one *solar year*. This period of time is also called a *tropical year*. We can mark off a period of one solar (or tropical) year by noting two successive times at which the sun reaches the same noontime altitude, and is moving in the same direction (that is, its altitude is either increasing or decreasing). Or we could use the time between two successive maximum altitudes (called *summer solstices*), or minimum altitudes *(winter solstices)*.

In actual practice, scientists have selected the time from one vernal equinox to the next as the duration of one solar year. (You will recall that the vernal equinox is the moment the sun crosses the celestial equator. At this moment, the altitude of the noontime sun at the equator is 90°.)

A year can also be defined as the time it takes the sun to return to the same position among the stars during its annual eastward motion. This would be the time the sun takes for one complete circuit of the ecliptic. This period is called one *sidereal year*. Because of a complex phenomenon called the precession of the equinoxes, a solar year and a sidereal year are not exactly the same. The sidereal year is about 20 minutes longer than the solar year. Again, for human convenience, we prefer the solar year for regulating the calendar, since we like to have the seasons fall in the same months year after year.

Moon Time and the Month. The cycle of the moon's phases was a very common basis for the yearly calendar in ancient times. One month was the interval from one full moon to the next. There were 12 months in a year, each with its own name. The month was not an exact unit of time, because the cycle of phases is not an exact number of days. It is about 29½ days, so any month might have either 29 or 30, depending on when the full phase was reached. Furthermore, the year is longer than 12 months, although shorter than 13. In order to keep the names of the months in step with the seasons, one of the months was repeated every two or three years. You can see that this was a rather awkward arrangement.

Our modern calendar also has a 12-month year, but the months are not related to the phases of the moon in any way. The lengths of the months in days have been adjusted so that one year is almost exactly 12 months.

SUMMARY

1. The frames of reference for measuring time are based mainly on apparent celestial motions.
2. Mean solar time differs from apparent solar time by an amount that varies throughout the year.

REVIEW QUESTIONS

Group A

1. Describe the apparent daily motion of the stars.
2. What is the daily rate of apparent motion of the stars?
3. Describe the annual, or yearly, motion of the stars.
4. What is the source of a star's energy?
5. How is the sun classified on the H-R diagram?
6. Describe the apparent annual motion and apparent diameter of the sun during the course of a year.
7. What is the maximum latitude at which the noontime sun is ever directly overhead?
8. Are the points of sunrise and sunset, and the length of daylight constant throughout the year?
9. Describe the moon's apparent daily motion through the stars.
10. How long does it take the moon to complete its cycle of motion through the stars and return to the same R.A.?
11. How long does it take the moon to complete its cycle of phases?
12. Does the moon's apparent diameter remain constant?
13. By what amount of time does mean solar time differ from apparent solar time?

Group B

1. Describe how you can show that a star has moved by making two observations.
2. What simple observations can you make of the sun to show that it apparently moves during a day? During a year?
3. a. What simple observations can you make of the moon to show that it apparently moves?
   b. Our time-keeping system is based mainly on the sun. Why don't we keep time using the stars or moon?
   c. Atomic clocks are being used to measure time. What advantage do they have over the sun?