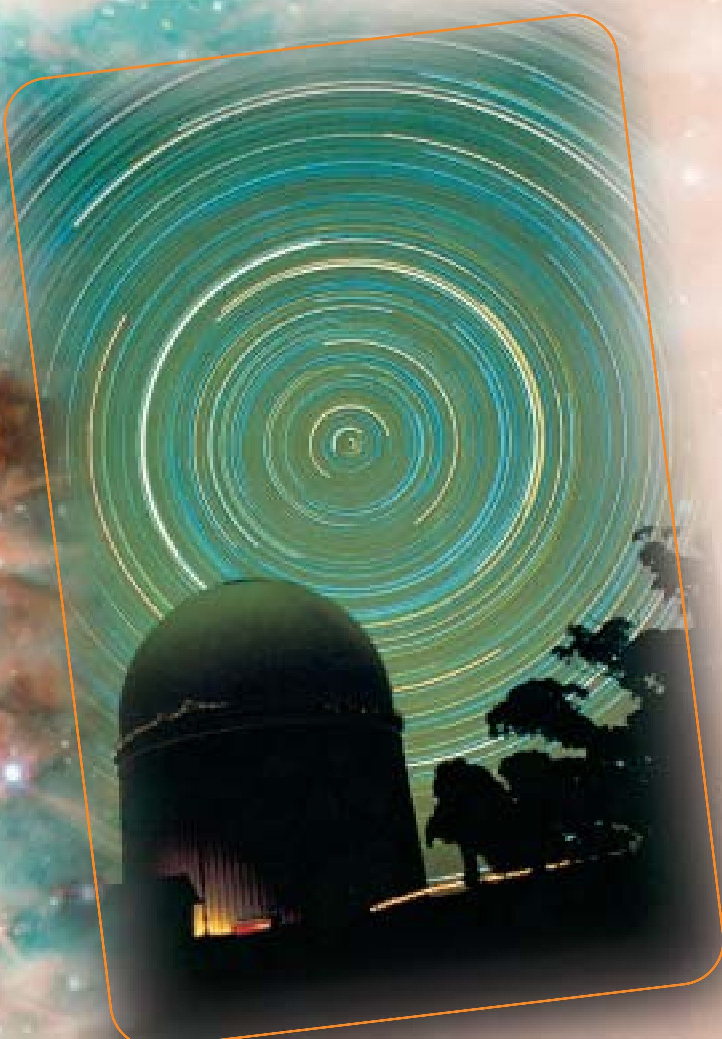
# 1 DISCOVERING THE NIGHT SKY

## IN THIS CHAPTER YOU WILL DISCOVER

- how astronomers map the night sky to help them locate objects in it
- that the Earth's spin on its axis causes day and night
- how the tilt of the Earth's axis of rotation and the Earth's motion around the Sun combine to create the seasons
- that the Moon's orbit around the Earth creates the phases of the Moon and lunar and solar eclipses
- how the year is defined and how the calendar was developed



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R I V U X G

**Circumpolar Star Trails**
This long exposure, taken from Australia's Siding Spring Mountain and aimed at the south celestial pole, shows the rotation of the sky. The building in the foreground houses the Anglo-Australian Telescope, one of the largest telescopes in the southern hemisphere. During the exposure, someone carrying a flashlight walked along the catwalk on the outside of the telescope dome. Another flashlight made the wavy trail at the ground level. (Anglo-Australian Observatory)

## WHAT DO YOU THINK?

1 Is the North Star—Polaris—the brightest star in the night sky?

2 Do astronomers regard constellations as simply the familiar patterns of stars in the sky first identified by ancient stargazers?

3 What causes the seasons?

4 How many zodiac constellations are there?

5 Does the Moon have a dark side that we never see from Earth?

6 Is the Moon ever visible during the daytime?

When you gaze at the sky on a clear, dark night, there seem to be millions of stars twinkling overhead. In reality, the unaided human eye can detect only about 6000 stars over the entire sky. At any one time, you can see roughly 3000 stars in dark skies, because only half of the stars are above the *horizon*, the boundary between the Earth and the sky.

WEB LINK 1.2 You probably have noticed patterns formed by bright stars and are probably familiar with some common names for these patterns, such as the bowl-shaped Big Dipper and broad-shouldered Orion. These recognizable patterns of stars, which we call constellations in everyday conversation, have names derived from ancient legends (Figure 1-1a).

# PATTERNS OF STARS

## 1-1 Constellations make locating stars easy

WEB LINK 1.3 You can orient yourself on Earth with the help of easily recognized constellations. For instance, if you live in the northern hemisphere, you can use the Big Dipper to find the direction north. To do this, locate the Big Dipper and imagine that its bowl is resting on a table. If you see the Dipper upside down in the sky, as you frequently will, imagine the dipper resting on an upside-down

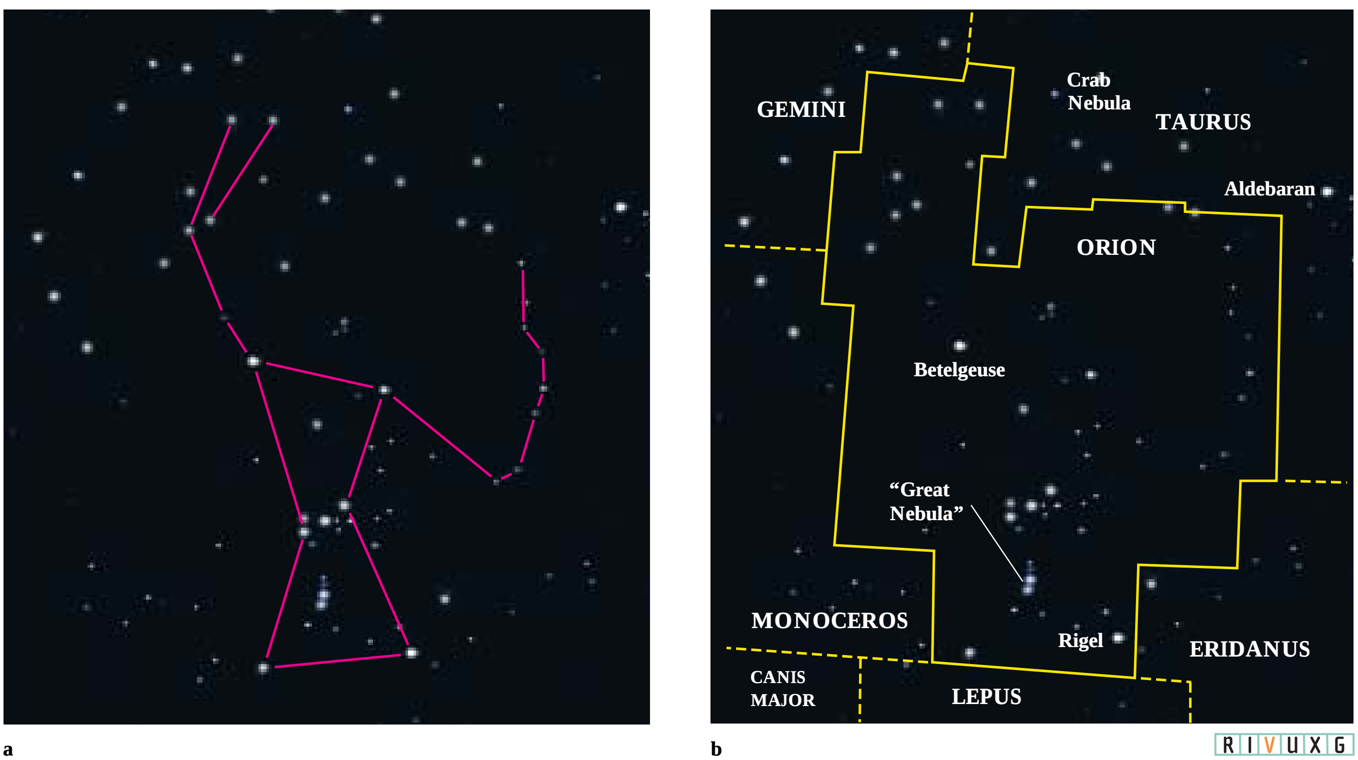



FIGURE 1-1 The Constellation Orion (a) The pattern of stars called Orion is a prominent winter constellation. From the Northern Hemisphere, it is easily seen high above the southern horizon from December through March. You can see in this photograph that the various stars have different colors, something to watch for when you observe the night sky. (b) The region of the sky called Orion and parts of other nearby constellations are depicted in this photograph. All the stars inside the boundary of Orion are members of that constellation. The celestial sphere is covered by 88 constellations of differing sizes and shapes. (John Sanford/Astrostock)

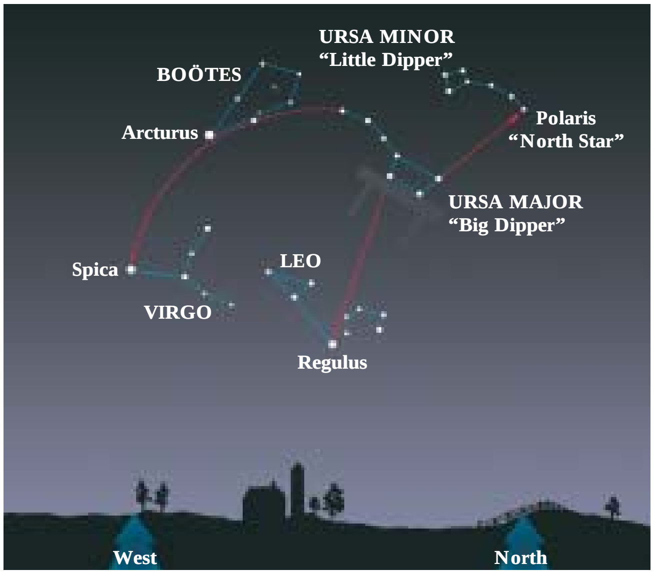



FIGURE 1-2 The Big Dipper as a Guide In the northern hemisphere, the Big Dipper is an easily recognized pattern of seven bright stars. This star chart shows how the Big Dipper can be used to point out the North Star as well as the brightest stars in three other constellations. While the Big Dipper appears right side up in this drawing, at other times of the night it appears upside down. Why does this happen?

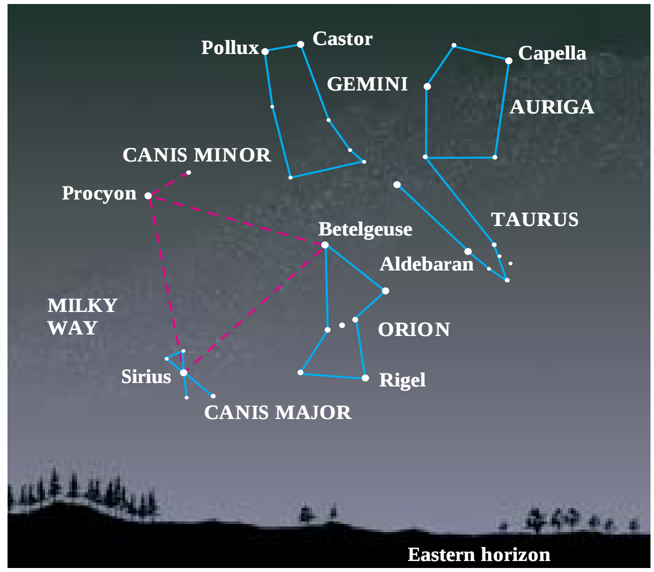



FIGURE 1-3 The Winter Triangle This star chart shows the eastern sky as it appears during the evening in December. Three of the brightest stars in the sky make up the winter triangle. In addition to the constellations involved in the triangle, Gemini (the Twins), Auriga (the Charioteer), and Taurus (the Bull) are also shown.

table above it. Locate the two stars of the bowl farthest from the Big Dipper's handle. These are called the *pointer stars*. Draw a mental line through these stars leading away from
1 the table, as shown in Figure 1-2. The first *moderately bright* star you then encounter is Polaris, also called the North Star because it is located almost directly over the Earth's north pole. So, while Polaris is not even among the 20 brightest stars (Appendix Table A-5), it is easy to locate. Whenever you face Polaris, you are facing north. East is then on your right, south is behind you, and west is on your left.

The Big Dipper example illustrates the fact that easily recognized constellations make it easy to locate other stars. The most effective way to do this is to use vivid visual connections, especially those of your own devising. For example, imagine gripping the handle of the Big Dipper and slamming its bowl through the imaginary table and onto the head of Leo (the Lion). Leo comprises the first group of bright stars your dipper encounters. As shown in Figure 1-2, the brightest star in this group is Regulus, the dot of the backward question mark that traces the lion's mane. As another example, put the Big Dipper back on its table and then follow the arc of its handle away from its bowl. The first bright star you encounter along that arc beyond the handle is Arcturus in Boötes (the Herdsman). Follow the same arc farther to the prominent bluish star Spica in Virgo (the Virgin). Spotting these stars is easy if you remember the saying "Arc to Arcturus and speed on to Spica."

During the winter months in the northern hemisphere, you can see some of the brightest stars in the sky. Many of them are in the vicinity of the "winter triangle," which connects bright stars in the constellations of Orion (the Hunter), Canis Major (the Larger Dog), and Canis Minor (the Smaller Dog), as shown in Figure 1-3. The winter triangle passes high in the sky at night during the middle of winter. It is easy to find Sirius, the brightest star in the night sky, by locating the belt of Orion and following a straight mental line from it to the left (as you face Orion). The first bright star that you encounter is Sirius.

Insight into Science **Flexible thinking** Part of learning science is learning to look at things from different perspectives. For example, when learning to identify the prominent constellations, be sure to learn them from different orientations (that is, with the star chart rotated at different angles), so that you can find them at different times of the night and the year.

The "summer triangle," which graces the summer sky as shown in Figure 1-4, connects the bright stars Vega in Lyra (the Lyre), Deneb in Cygnus (the Swan), and Altair in Aquila (the Eagle). A conspicuous portion of the Milky Way forms a beautiful background for these constellations, which are

## GUIDED DISCOVERY The Stars and Constellations

Many students take an introductory astronomy course expecting to be taught the familiar stars and constellations, something most teachers just don't have time to cover. You can, however, learn them on your own using two helpful techniques for memorizing the night sky.

1. Observe easily identified constellations and use these to find nearby, lesser-known ones. For example, you may not remember where the star Aldebaran in Taurus is in the sky, but if you remember that Orion is fighting Taurus, you can easily locate Aldebaran by following a line defined by the belt of Orion to the right (away from Sirius). The first bright star you encounter is Aldebaran.
2. Make your own connections between the constellations. Have fun while you're doing it. Chances are that you will remember the phrase "slam the Big Dipper's bowl downward to hit Leo the Lion on the head" rather than "the first bright group of stars directly below the Big Dipper is Leo."

A very efficient way to learn the constellations is to use the board and card game *Stellar 28*. In addition, astronomy computer programs such as *Starry Night Backyard™*, included with this text, are available. *Starry Night Backyard™* shows many things besides what constellations are up at night, including the motion, location, and phases of the planets; the location of deep sky objects, such as nebulae; and the sky as seen from any location on Earth on any date.

Another good way to familiarize yourself with the night sky is to use star charts to see which constellations are up each night. You will find a set of star charts from the *Griffith Observer* magazine at the front and back of this book. To use the charts, first select the one that best corresponds to the date and time of your observation. Take the chart outside at night and compare it directly with the sky. Hold the chart vertically and turn it so that the direction you are facing shows at the bottom. Using a flashlight with a red plastic coating over the light will make it easier to read the chart without constricting your vision. You will find stargazing a surprisingly enjoyable experience.

### Stars' Technical Names

Astronomers assign all stars technical names, based on the constellations they are in. You can learn more about how these assignments are made at the adjacent More to Know link.

nearly overhead during the middle of summer at midnight. For more on the constellations see the above Guided Discovery Box.

Astronomers require more accuracy in locating dim objects than is possible simply by moving from constellation to constellation. They have therefore created a celestial map and applied a coordinate system to it analogous to the coordinate system of north-south latitude and east-west longitude used to navigate on the Earth. If a star's celestial coordinates are known, it can be quickly located. For such a sky map to be useful in finding stars, the stars must be fixed on it as cities are fixed on maps of the Earth.

## 1-2 The celestial sphere aids in navigating the sky

If you look at the night sky year after year, you will see that the stars do indeed appear fixed relative to each other. Furthermore, throughout each night the entire pattern of stars appears to rigidly orbit the Earth. We employ this Earth-based view of the heavens

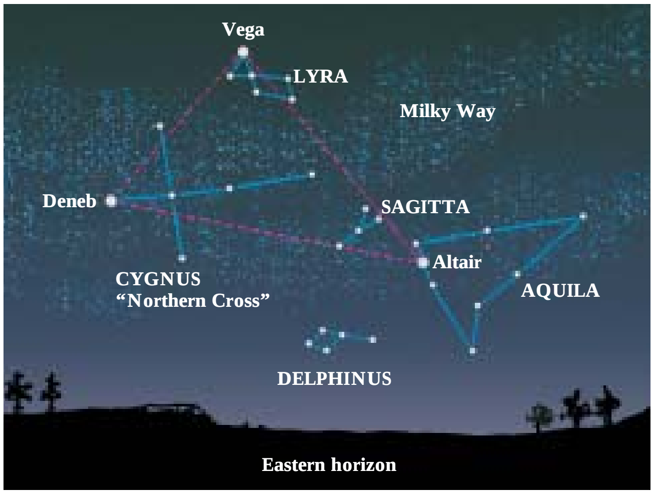



FIGURE 1-4 The Summer Triangle This star chart shows the northeastern sky as it appears in the evening in June. In addition to the three constellations involved in the summer triangle, the faint stars in the constellations of Sagitta (the Arrow) and Delphinus (the Dolphin) are also shown.

to make celestial maps by pretending that the stars are attached to the inside of an enormous hollow shell, the **celestial sphere,** with the Earth at its center (Figure 1-5).

We discussed the common usage of the word *constella-*
2 *tion* at the beginning of this chapter. Astronomers use the word technically to describe an entire region of the sky and all the objects in that region (see Figure 1-1b). The celestial sphere is divided into 88 unequal regions, and these regions are what astronomers refer to when they use the term **constellations.** (Astronomers call the traditional star patterns *asterisms* rather than constellations when there is a danger of confusion.) Some constellations (like Ursa Major) are very large, while others (like Sagitta) are relatively small. To locate stars, we might say "Albireo in the constellation Cygnus," much as we would refer to "Ithaca in New York State."

The stars seem fixed on the celestial sphere only because of their remoteness. In reality, they are at widely varying distances from the Earth, and they do move relative to each other. But we neither see their motion nor perceive their relative distances because the stars are so far from here. You can understand this by imagining a jet plane a kilometer overhead traveling at 1000 kilometers (620 miles) an hour across the sky. Its motion is unmistakable. But a plane moving at the same speed along the distant horizon appears to be moving about a hundred times more slowly. And an object at the distance of the Sun traveling at the same speed and moving across the sky would appear to be going nearly a hundred million times more slowly than the plane overhead.

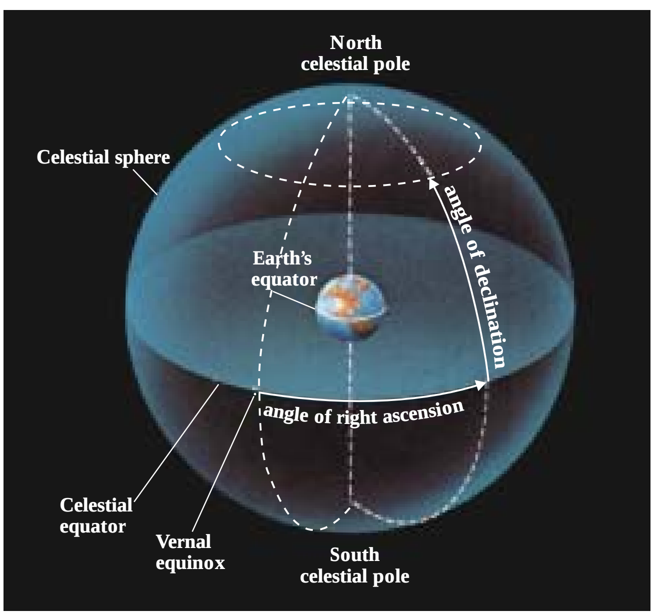



FIGURE 1-5 The Celestial Sphere The celestial sphere is the apparent "bowl" or hollow sphere of the sky. The celestial equator and poles are projections of the Earth's equator and axis of rotation out into space. The north celestial pole is therefore located directly over the Earth's north pole, while the south celestial pole is directly above the Earth's south pole.

The stars (other than the Sun) are all more than 40 trillion kilometers (25 trillion miles) from us. Therefore, although the patterns of stars in the sky do change, their great distances prevent us from seeing those changes over the course of a human lifetime. Thus, as unrealistic as it is, the celestial sphere is so useful for navigating the heavens that it is used by astronomers even at the most sophisticated observatories around the world.

As shown in Figure 1-5, we can project key geographic features from Earth out into space to establish directions and bearings. If we expand the Earth's equator onto the celestial sphere, we obtain the **celestial equator.** The celestial equator divides the sky into northern and southern hemispheres, just as the Earth's equator divides the Earth into two hemispheres. We can also imagine extending the Earth's north and south poles out into space along the Earth's axis of rotation. Doing so gives us the **north celestial pole** and the **south celestial pole,** also shown in Figure 1-5. With the celestial equator and poles as reference features, astronomers denote the position of an object in the sky in much the same way that latitude and longitude are used to specify a location on Earth.

Just as we need two coordinates (latitude and longitude) to find any location on Earth, two coordinates are needed to locate any object on the celestial sphere. The equivalent to latitude on Earth is **declination** on the celestial sphere. It is measured north or south of the celestial equator. The equivalent of longitude on Earth is **right ascension** on the celestial sphere, measured around the celestial equator (see Figure 1-5).

We will see later in this chapter that the Sun moves in a circle around the celestial sphere during the course of a year. The celestial equator and the Sun's path intersect at two points. The equivalent on the celestial sphere of the Earth's prime meridian (from which degrees of longitude are measured on Earth) is where the Sun crosses the celestial equator moving northward. Angles of right ascension are measured from this point, called the *vernal equinox* (Figure 1-5).

In navigating on the celestial sphere, astronomers measure the distance between objects in terms of angles. If you are not familiar with measuring the separation between objects using this method, read An Astronomer's Toolbox 1-1.

## EARTHLY CYCLES

The everyday rhythms of the Earth and all life on it arise from three celestial motions: the Earth's rotation, which causes day and night; the Earth's revolution around the Sun, which creates the seasons and the year; and the Moon's revolution around the Earth, which creates the lunar phases,

# AN ASTRONOMER'S TOOLBOX 1-1

## Observational Measurements Using Angles

Astronomers have inherited many useful concepts from antiquity. Among other things, ancient mathematicians invented angles and a system of angular measure that is still used to denote the positions and apparent sizes of objects in the sky. To locate stars, for example, we do not need to know their distances from Earth (which are all different). All we need to know is the angle from one star to another in the sky, a property that remains fixed over our lifetimes.

An **arc angle,** often just called an **angle,** is the opening between two lines that meet at a point. Angular measure is a method of describing the size of an angle. The basic unit of angular measure is the **degree,** designated by the symbol °. A full circle is divided into 360°. A right angle measures 90°. As shown in the figure below, the angle between the two "pointer stars" in the Big Dipper is about 5°.

Astronomers also use angular measure to describe the apparent sizes of celestial objects. For example, imagine looking up at the full Moon. The angle covered by the Moon's diameter is nearly $1/2°$. We therefore say that the **angular diameter,** or angular size, of the Moon is $1/2°$. Alternatively, astronomers say that the Moon "subtends" an angle of $1/2°$. In this context, *subtend* means "to extend across."

The adult human hand held at arm's length provides a means of estimating angles. For example, your fist covers an angle of 10°, whereas the tip of your finger is about 1° wide. Various segments of your index finger extended to arm's length can be similarly used to estimate angles a few degrees across as shown in the figure below, right.

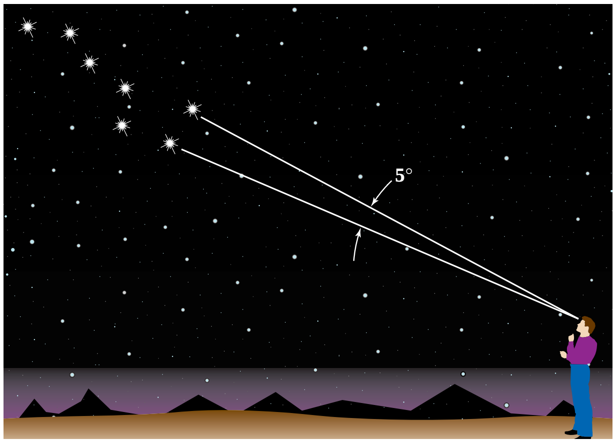
To talk about smaller angles, we subdivide the degree into 60 arcminutes (abbreviated 60 arcmin or 60´). An arcminute is further subdivided into 60 arcseconds (abbreviated 60 arcsec or 60´´). A dime viewed face-on from a distance of 1 mile has an angular diameter of about 2 arcsec. From everyday experience, we know that an object looks big when it is nearby but small when it is far away. The angular size of an object therefore does not necessarily tell you anything about its actual physical size. For example, the fact that the Moon's angular diameter is $1/2°$ does not tell you how big the Moon really is. But if you also happen to know the distance to the Moon, then you can calculate the Moon's physical diameter. In general, the physical diameter of an object can be calculated from the equation:

$$\text{physical diameter} = \text{distance} \times \tan(\text{angular diameter})$$

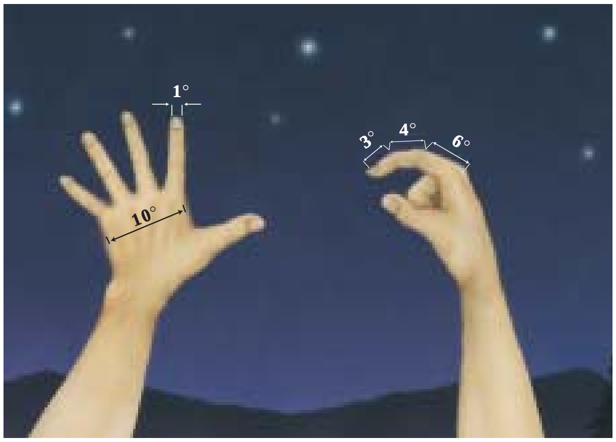
where tan (angular diameter) means the tangent of the angle denoted "angular diameter." In the Moon's case, using a measured distance (Appendix Table A-3) of 384,400 km and an angular diameter of $1/2°$, we find the diameter to be roughly 3350 km. The difference between this and the exact diameter of 3476 km is due primarily to the approximate value of $1/2°$ that we have used.

*Try these questions:* The Sun is $1.5 \times 10^8$ km away and has a diameter of $1.4 \times 10^6$ km. How large an angle does it make in our sky? How is that relevant to the arc angle of the Moon in our sky? What arc angle would the Moon make in our sky if it were twice as far away? Half as far?

(Answers appear at the end of the book.)




The Big Dipper The angular distance between the two "pointer stars" at the front of the Big Dipper is about 5°. For comparison, the angular diameter of the Moon is about $1/2°$.




Estimating Angles with the Human Hand Various parts of the adult human hand extended to arm's length can be used to estimate angular distances and sizes in the sky.

the cycle of tides, and the spectacular phenomena we call eclipses.

Contrary to common sense, the seasons are not caused by the change in the Earth's distance from the Sun. If the seasons were caused by the changing distance from the Earth to the Sun, all parts of the Earth should have the same seasons at the same time. In fact, the northern and southern hemispheres have exactly opposite seasons. Furthermore, the Earth is closest to the Sun on January 3 of each year—the dead of winter in the northern hemisphere! We will explore the seasons further in Section 1-6.

Insight into Science **Expect the unexpected** Many phenomena in the universe defy commonsense explanations. The process of science requires that we question the obvious, that is, what we think we know. The fact that the changing distance from the Earth to the Sun has a negligible effect on the seasons is an excellent example.

## 1-3 Earth's rotation causes the stars to appear to move

The Earth spins on its axis. Such motion is called **rotation.** The Earth's 24-hour rotation causes the constellations—as well as the Sun, Moon, and planets—to appear to rise on the eastern horizon, move across the sky, and set on the western horizon. Bear in mind that the Sun and Moon rise due east and set due west only on certain days of the year. The **diurnal motion,** or daily motion, of the celestial bodies is apparent in time-exposure photographs, such as the one that opens this chapter. The Earth's rotation causes day and night because it makes the Sun appear to follow a diurnal path across the sky.

People who spend time outdoors at night are familiar with the diurnal motion of the stars. Take a friend outside on a clear, warm night to observe it for yourself. Soon after dark, find a spot away from bright lights, and note the constellations in the sky relative to some prominent landmarks near you on Earth. A few hours later, check again from the same place. You will find that the entire pattern of stars (as well as the Moon, if it is visible) has shifted. New constellations will have risen above the eastern horizon, while other constellations will have disappeared below the western horizon. If you check again just before dawn, you will find the stars that were just rising in the east when the night began are now low in the western sky.

Different constellations are visible at night during different times of the year. This occurs because the Earth orbits, or *revolves,* around the Sun. **Revolution** is the motion of any astronomical object around another astronomical object. The Earth takes one year, or about 365¼ days, to go once around the Sun. As a result of this motion, the darkened, nighttime side of the Earth is turned toward different parts of the heavens at different times of the year. (We explore this further in Section 1-5.) Another result of the Earth's motion around the Sun is that every star rises approximately 4 minutes earlier each night than it did the night before.

We spoke earlier of stars rising on the eastern horizon and setting on the western horizon. Depending on your latitude, some of the stars and constellations never disappear below the horizon. Instead, they trace complete circles in the sky over the course of each night. To understand why this happens, imagine that you are standing on the Earth's north pole at night. Looking straight up, you see Polaris. Wherever you are, objects directly overhead are said to be at your **zenith.** Because the Earth is spinning around its axis directly under your feet, all the stars appear to move from left to right in horizontal rings around you. The exception is Polaris, which always remains at the north pole's zenith. As seen from the north pole, no stars rise or set (Figure 1-6). They just seem to revolve around Polaris in horizontal circles. Stars and constellations that never go below the horizon are called **circumpolar.** All stars visible from the north or south pole are circumpolar.

Now visualize yourself at the equator. All the stars appear to rise straight up in the eastern sky and set straight down in the western sky (Figure 1-7). Polaris is barely visible on the northern horizon. While Polaris never sets, all the other stars do, and therefore none of the stars are circumpolar as seen from the equator.

You may already have concluded from these two mental exercises that the angle at which the stars rise and set

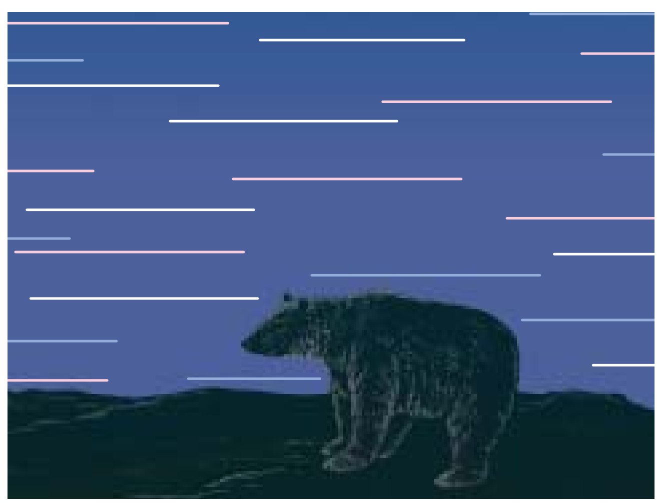


FIGURE 1-6 Motion of Stars at the Poles Because the Earth rotates around its poles, stars seen from these locations appear to move in huge, horizontal circles. This is the same effect you would get by standing up in a room and spinning around; everything would appear to move in circles around you. At the north pole stars move left to right, while at the south pole they move right to left.

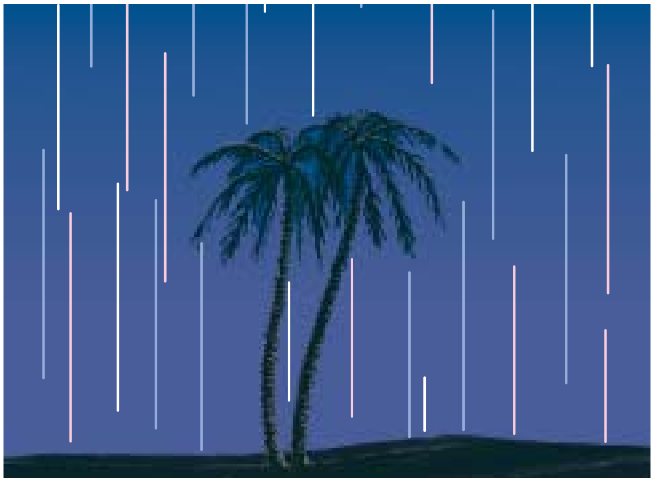


**FIGURE 1-7** Rising of Stars at the Equator Standing on the equator, you are perpendicular to the axis around which the Earth rotates. As seen from there, the stars rise straight up on the eastern horizon and set straight down on the western horizon. This is the same effect you get when driving straight over the crest of a hill; the objects on the other side of the hill appear to move straight upward as you descend.

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**FIGURE 1-8** Rising and Setting of Stars at Middle North Latitudes Unlike the motion of the stars at the poles (see Figure 1-6), the stars at all other latitudes do change angle above the ground throughout the night. The time-lapse photograph shows stars setting. The latitude determines the angle at which the stars rise and set. (David Miller/DMI.)

depends on your viewing latitude. Figure 1-8, for example, shows stars setting at 35° north latitude. In Orono, Maine (44°45´ north latitude), where this book was written, stars rise at an angle of nearly 45° to the eastern horizon and set at an angle of 45° to the western horizon. Polaris is fixed at 45° above the horizon in Orono's northern sky, not at the zenith there, as it is at the north pole or on the horizon as seen from the equator. As another example, except for those stars in the upper corners, the stars whose paths are shown in the photograph on page 14 are circumpolar because they are visible all night, every night.

If you live in the northern hemisphere, Polaris is always located above your northern horizon at an angle equal to your latitude. Only the stars and constellations that pass between Polaris and the land directly below it are circumpolar. The farther north you go in the northern hemisphere, the greater the number of stars and constellations that are circumpolar. The opposite is true in the southern hemisphere.

## 1-4 The rate at which the Earth rotates determines the length of the day

The Sun's daily motion through the sky provided our ancestors' earliest reference for time, because the Sun's location determines whether it is day or night, whether we are awake or asleep, and whether it is time for breakfast or dinner. In other words, the Sun determines the length of the **solar day,** upon which our 24-hour day is based. However, the length of the solar day varies throughout the year. The Sun is not a perfect timekeeper, because the Earth's orbit around it is not circular, as we will study in Chapter 3. Because the Earth moves slightly more rapidly along its orbit when it is near the Sun than when it is farther away, the speed of the Sun across the sky also varies throughout the year. Using the average time interval between consecutive noontimes to determine the solar day corrects this problem, and this average defines our 24-hour day.

Astronomically, noon is defined as the instant when the Sun is highest in the sky. However, at different longitudes the Sun is highest at different times. Thus, astronomical noon in New London, Connecticut, occurs slightly earlier than it does in New Haven, Connecticut. Before the advent of time zones, local time was based on astronomical noon. To travel from New London west to New Haven by train, for example, you had to know the departure time at New London, using New London time, as well as the arrival time in New Haven (say, if someone was going to meet you) in New Haven time. Such time considerations became very confusing and burdensome as society became more complex. Fortunately, in the late nineteenth century, time zones were established to remove this problem. In a **time zone,** everyone agrees to set their clocks alike. Time zones, originally developed for scheduling rail transportation, are based on the time at 0° longitude in Greenwich, England, a location called the *prime meridian.* With some variation due to geopolitical boundaries, every 15° of longitude around the globe begins a new time zone. The resulting 24 time zones are shown in Figure 1-9. Going from one time zone to the

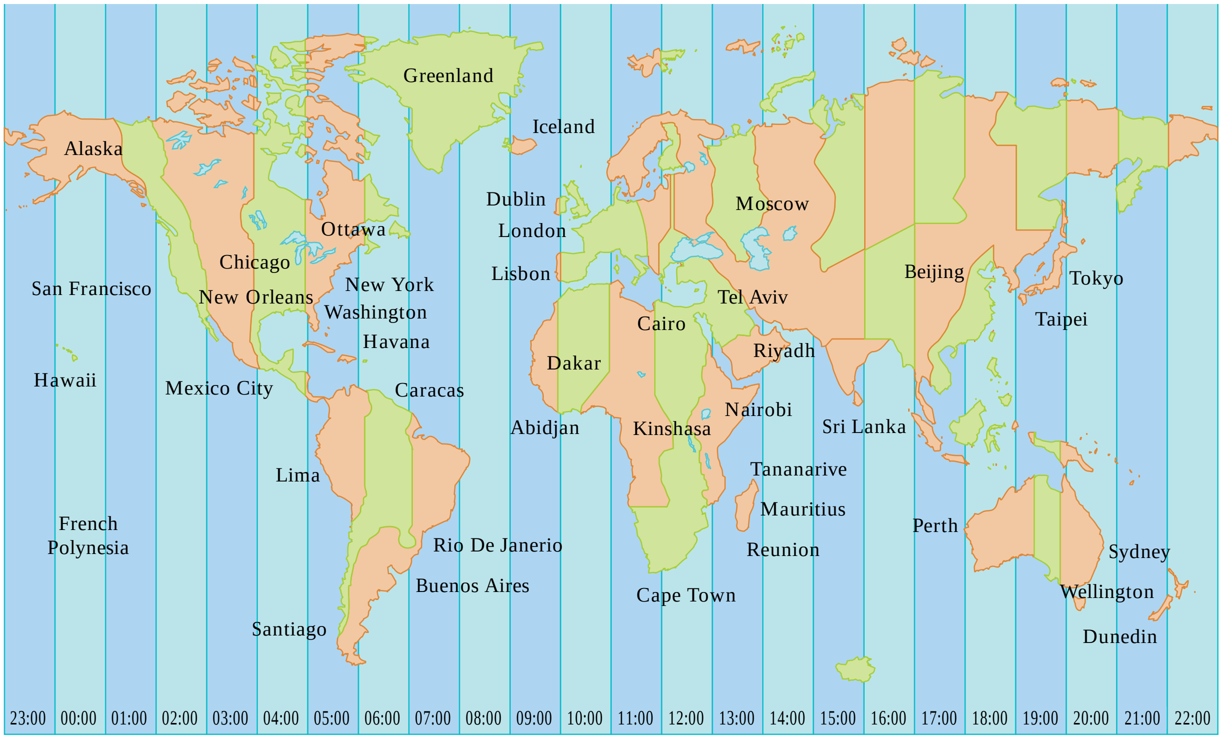


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**FIGURE 1-9** Time Zones of the World For convenience, Earth's 360° circumference is divided into 24 time zones. Ideally, each time zone would run due north-south. However, political considerations make some zones irregular. Indeed, there are even a few zones only a half hour wide.

next usually requires you to change the time on your wristwatch by exactly 1 hour.

## 1-5 The Earth's orbit determines the length of the year and which stars are up at night

Just as the day originates in the Earth's rotation, the year is the unit of time based on the Earth's revolution about the Sun. The Earth does not take exactly 365 days to orbit the Sun, so the year is not exactly 365 days long. Ancient astronomers realized that the length of a year is approximately $365\frac{1}{4}$ days. The Roman statesman Julius Caesar established the system of leap years to account for this extra quarter of a day. By adding an extra day to the calendar every four years, Caesar hoped to ensure that seasonal astronomical events, such as the beginning of spring, would occur on the same date year after year.

Caesar's system would have worked if the year were exactly $365\frac{1}{4}$ days long and the Earth's rotation axis never changed direction. Unfortunately, this is not the case. Thus, over time, a discrepancy accumulated between Caesar's "Julian" system and actual time. Annual events began to fall on different dates each year. To straighten things out, Pope Gregory XIII reformed the Julian calendar in 1582. He began by dropping ten days (October 5, 1582, was proclaimed to be October 15, 1582), which brought the first day of spring back to March 21. Next, he modified Caesar's system of leap years. Caesar had added February 29 to every calendar year that is evenly divisible by four. For example, 1988, 1992, and 1996 were all leap years with 366 days. But this system produces an error of about three days every four centuries. To solve the problem, Pope Gregory decreed that century years would be leap years only if evenly divisible by 400. For example, the years 1700, 1800, and 1900 were not leap years under the improved Gregorian system. But the year 2000—which can be divided evenly by 400—was a leap year.

We use the Gregorian system today. It assumes that the year is 365.2425 mean solar days long, which is very close to the length of the *tropical year,* defined as the time interval from one vernal equinox to the next. In fact, the error is only one day in every 3300 years. That won't cause any problems for a long time. Two major impacts of our annual journey around the Sun are the changing stars in our night sky and the unfolding of the seasons.

Figures 1-10a and b show why different constellations are visible at night during different times of the year. When the Sun is "in" Virgo (September 18–November 1), the hemisphere containing the Sun and the constellations around Virgo are in daylight (Figure 1-10a). When the Sun is up, so are Virgo and the surrounding constellations, and so we cannot see them. During that time of year, the constellations on the other side of the celestial sphere, centered on the constellation Pisces, are in darkness. So, when the Sun is "in" Virgo, Pisces and the constellations around it are high in our sky at night.

Six months later, when the Sun is "in" Pisces, that half of the sky is filled with daylight, while Virgo and the constellations around it are high in the night sky (Figure 1-10b). These arguments apply everywhere on Earth at the same time because the Sun moves through the zodiac constellations very slowly as seen from Earth, taking a year to make one complete circuit.

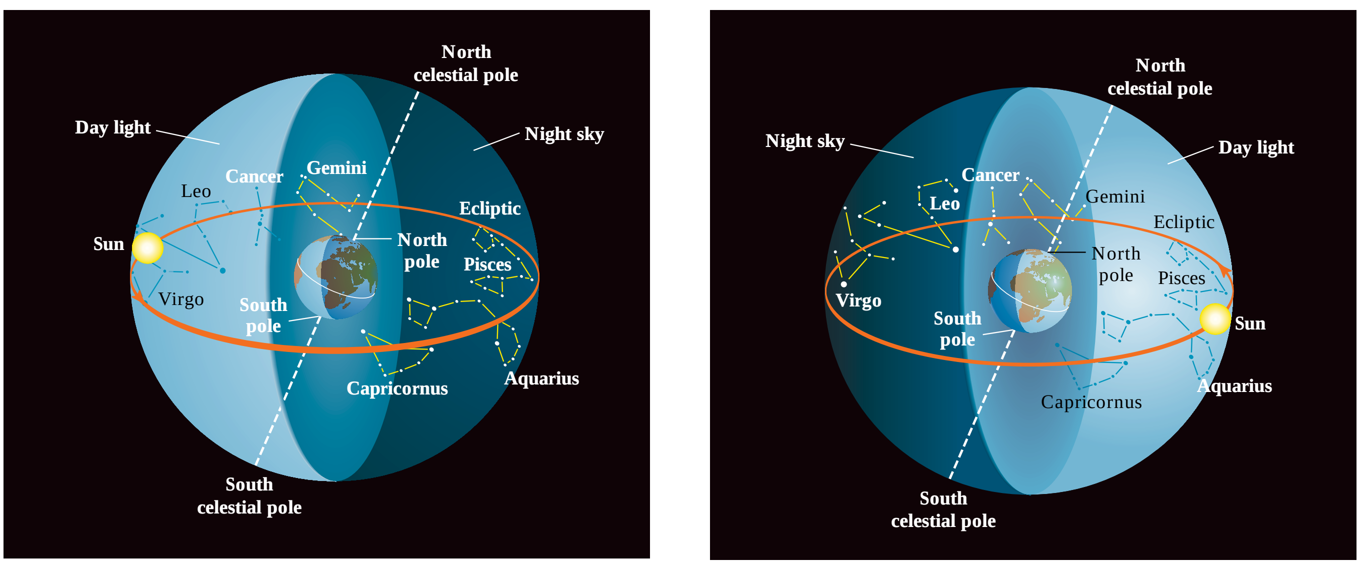
## 1-6 The seasons result from the tilt of the Earth's rotation axis combined with its revolution around the Sun

The seasons are due to the combined effects of the Earth's
3 revolution and the tilt of the Earth's axis of rotation relative to the plane of our orbit around the Sun. Imagine that you could see the stars even during the day, so that you could follow the Sun's apparent motion against the background constellations throughout the year. (The Sun appears to move among the stars, of course, because the
around it.)

From day to day, the Sun would tra
path on the celestial sphere. You can
your *Starry Night Backyard*™ software
*Go/Atlas*, locking on the Sun, zooming out to about 90° of the sky, setting the timestep to 3 days, and stepping along or setting the time to run continuously. You will see the stars moving relative to the Sun, meaning that the Sun is moving along the ecliptic around the celestial sphere. As you can see in Figure 1-11a, the ecliptic makes a closed circle bisecting the celestial sphere.

The term **ecliptic** has another use in astronomy. The Earth orbits the Sun in a plane also called the ecliptic. You can see that the two ecliptics exactly coincide. Imagine yourself on the Sun watching the Earth move day by day. The path of the Earth on the celestial sphere as seen from the Sun is precisely the same as the path of the Sun as seen from the Earth (Figure 1-11b).

**Insight into Science** **Define your terms** The words "ecliptic" and "constellation" have more than one scientific meaning. Most often, however, scientists restrict words to one well-defined meaning, because more than one meaning can lead to misunderstandings. Be sure that you understand each word in astronomy and how to use it.




a

b

FIGURE 1-10 Why different constellations are visible at different times of the year. (a) On autumnal equinox each year, the Sun is in the constellation Virgo. As seen from Earth, that part of the sky is in daylight and we see stars only on the other half of the sky, centered around the constellation Pisces. (b) Six months later, the Sun is in Pisces. This side of the sky is bright, while the side centered on Virgo is now in darkness.

## MOVIE MISCONCEPTIONS

*Austin Powers: The Spy Who Shagged Me* (New Line Cinema, 1999)
(The Everette Collection)

**The year is 1999 and the international man of mystery Austin Powers and the sinister Dr. Evil are back in *Austin Powers: The Spy Who Shagged Me*. In the movie there is a scene in Doctor Evil's secret lair in which the evil doctor shows his staff how he plans to put a "laser" on the Moon and use it to destroy cities on Earth. In making his presentation, he uses a large orrery consisting of a four-foot diameter model of the Earth fixed in a basket, around which a model of the Moon is free to revolve. The United States is clearly visible on the upper half of the Earth model, meaning that the north celestial pole is above the set. The model of the Earth does not move. The evil doctor explains his plan and then pushes the Moon clockwise around the Earth until it is above the United States. What is wrong with the astronomy described so far?**

**Despite the error that you have just identified, the Moon follows a westward path around the Earth, as would be seen correctly by someone standing on that fixed model of the Earth in the scene. Explain why the Moon follows the correct path around the model of the Earth, despite the error above.**

**(Answers appear at the end of the book.)**

The celestial equator and the ecliptic are different circles on the celestial sphere because the Earth's axis is tilted $23\frac{1}{2}°$ away from a line perpendicular to the ecliptic, as shown in Figure 1-12. Except for tiny changes each year, discussed below, the Earth maintains this tilted orientation as it orbits the Sun. Polaris is above the north pole throughout the year. For half the year, the northern hemisphere is tilted toward

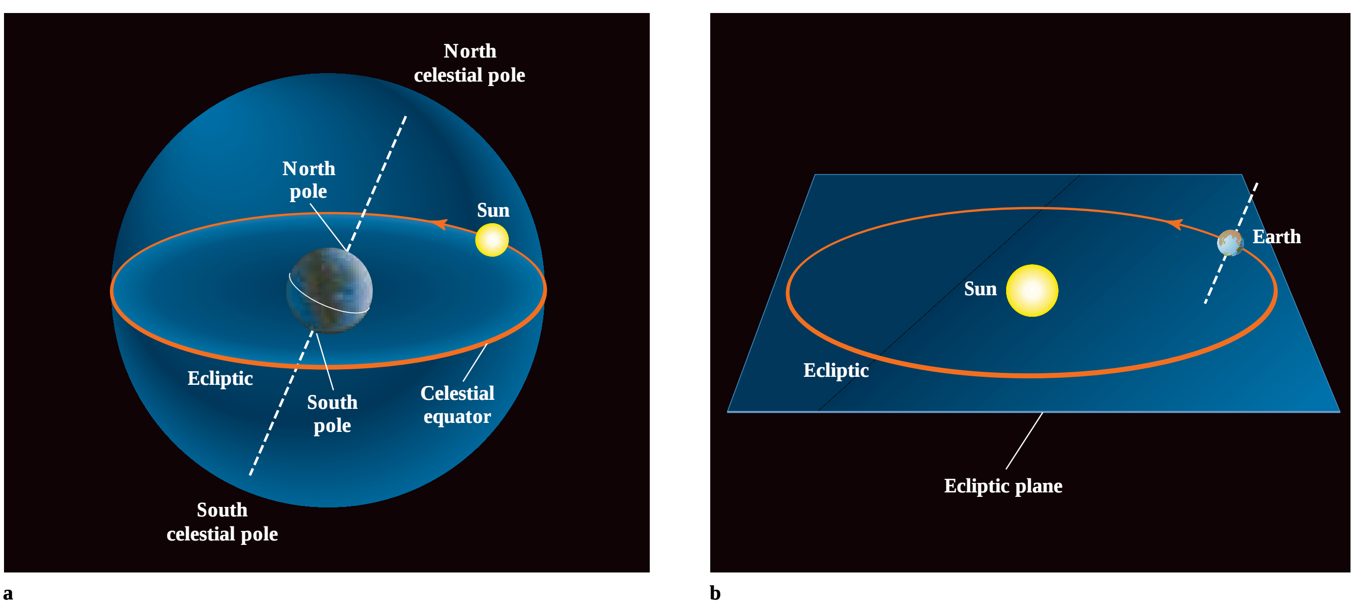
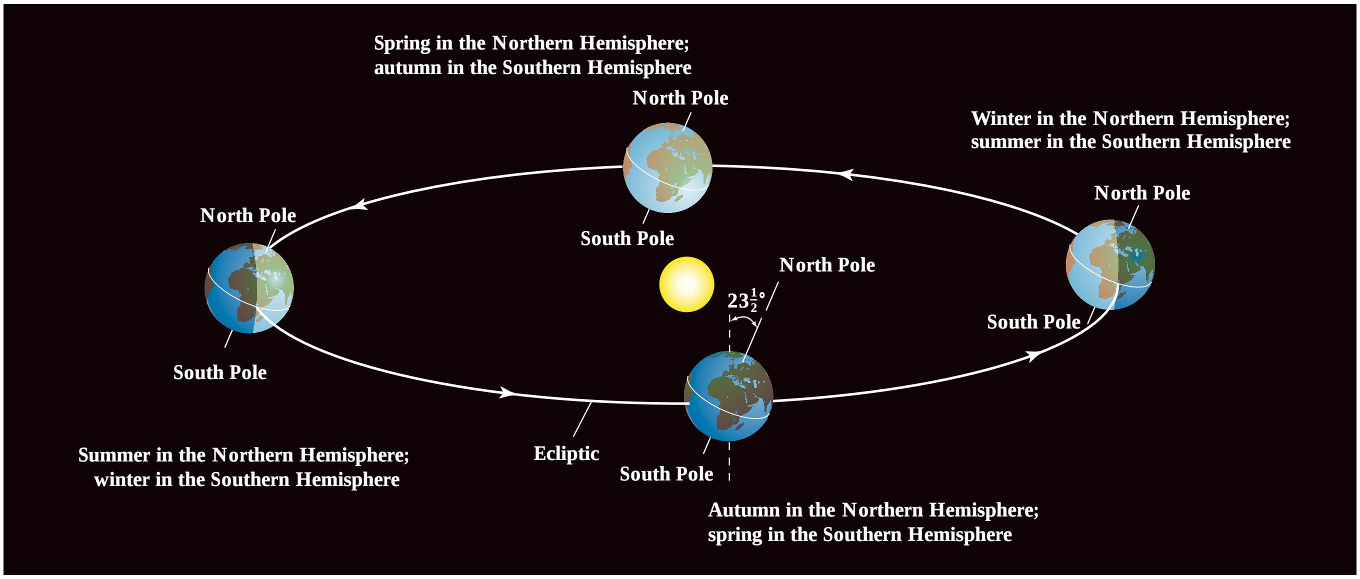



FIGURE 1-11 The Ecliptic (a) The ecliptic is the apparent annual path of the Sun on the celestial sphere. (b) The ecliptic is also the plane described by the Earth's path around the Sun. The planes created by the two ecliptics exactly coincide. As in (a), the rotation axis of the Earth is shown here tilted $23\frac{1}{2}°$ from being perpendicular to the ecliptic.




ANIMATION 1.2

**FIGURE 1-12** The Tilt of the Earth's Axis The Earth's axis of rotation is tilted $23\frac{1}{2}°$ from being perpendicular to the plane of the Earth's orbit. The Earth maintains this orientation (with its north pole aimed at the north celestial pole near the star Polaris) throughout the year as it orbits the Sun. Consequently, the amount of solar illumination and the number of daylight hours at any location on Earth vary in a regular fashion throughout the year.

the Sun, and, as a result, the Sun rises higher in the northern hemisphere's sky than it does during the other half of the year. Equivalently, when the Sun is tilted toward the southern hemisphere, it rises higher in the southern hemisphere's sky (Figure 1-13). By the way, the seasons are not caused by the fact that one hemisphere is slightly closer to the Sun than the other—that difference in distance is much, much too small to cause any temperature difference.

MORE TO KNOW 1.2

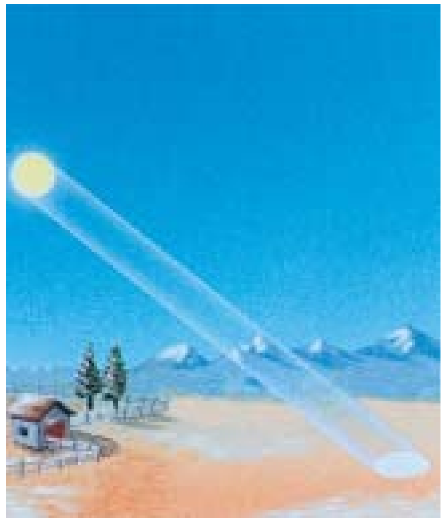
The Height of the Sun

The higher the Sun rises during the day, the more daylight hours. During these longer periods of daylight, more light and heat energy from the Sun strike that hemisphere than during the seasons when the north pole is pointed away from the Sun, and, therefore, the Sun does not rise nearly as high in the sky. Furthermore, when the Sun is higher in the sky, its energy is more concentrated on the Earth's surface (Figure 1-14). The temperature in any region on Earth is determined by the duration of daylight there and the height of the Sun in the sky.

Because of the tilt of the Earth's axis of rotation, the ecliptic and the celestial equator are inclined to each other by $23\frac{1}{2}°$, as shown in Figure 1-15. These two circles intersect at only two points, which are exactly opposite each other on the celestial sphere. Both points are called **equinoxes**

R I V U X G

**FIGURE 1-13** The Height of the Sun The maximum height of the Sun in the sky varies throughout the year because of the $23\frac{1}{2}°$ tilt of the Earth's axis. This photograph shows the height of the Sun in the sky at the same clock time at 10-day intervals throughout the year, as well as its changing east-west location. The east-west variation in the Sun's location is caused by its rising, reaching its maximum height in the sky, and setting at different places throughout the year (See Figure 1-16). (Dennis Di Cicco)

a b

**FIGURE 1-14** The Energy Deposited by the Sun In the northern hemisphere, the angle of the Sun above the southern horizon determines how much heat and light strike each square meter of ground. In the southern hemisphere, the Sun's angle is measured above the northern horizon. (a) During the summer at middle latitudes, a shaft of sunlight illuminates a nearly circular patch of ground at noon. (b) During the winter, the same shaft of sunlight at noon strikes the ground at a steeper angle, spreading the same amount of sunlight over a larger, oval shape. Because the sunlight's energy is diluted over a larger area, the ground receives less heat during the winter than during the summer.

(from the Latin words meaning "equal night"), because when the Sun appears at either point, it is directly over the Earth's equator, and there are 12 hours of daytime and 12 hours of nighttime everywhere on Earth on that day.

The **vernal equinox** occurs around March 21, when the Sun crosses the celestial equator heading northward; the **autumnal equinox** occurs six months later, around September 22, with the Sun heading southward. The vernal equinox is the "prime meridian" of the celestial sphere, as discussed earlier. The midpoints between the vernal and autumnal equinoxes along the ecliptic are significant as well. The point on the ecliptic farthest north of the celestial equator is the **summer solstice.** It signals the day of the year in the northern hemisphere with the largest number of daylight hours (and the fewest daylight hours in the southern hemisphere). The Sun reaches this point around June 21 each year. Six months later, around December 21, the Sun is farthest south of the celestial equator at the **winter solstice,** the day of the year in the northern hemisphere with the fewest daylight hours (and the most daylight hours in the southern hemisphere).

The Sun is highest in the northern sky on the summer solstice. This marks the beginning of summer in the northern hemisphere. As the Sun moves southward, the amount of daylight decreases. The autumnal equinox marks a midpoint in the amount of heat deposited by the Sun onto the northern hemisphere and is the beginning of autumn. When the Sun reaches the winter solstice, it is lowest in the northern sky and is above the horizon for the shortest time of the year. This is the beginning of winter. Returning northward, the Sun crosses the celestial equator once again on the vernal equinox, the beginning of spring.

Figure 1-16 shows the seasonal changes in the Sun's daily path across the sky. On the first day of spring or autumn (when the Sun is at one of the equinoxes), the Sun

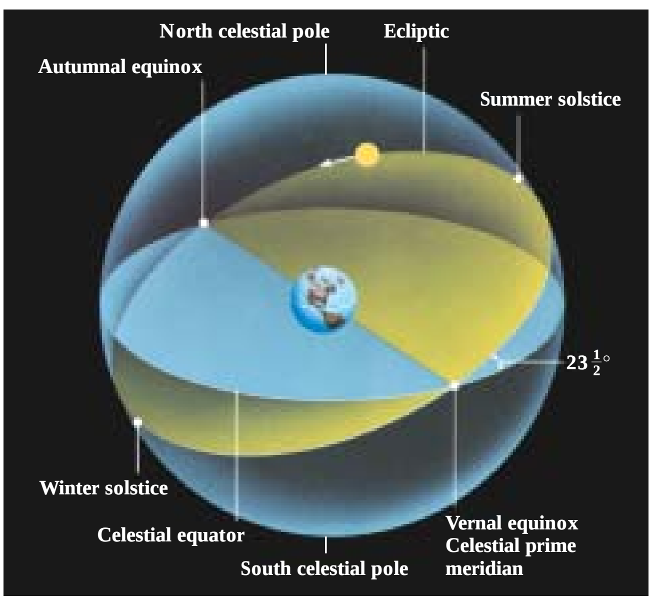



**FIGURE 1-15** The Seasons Are Coupled to Equinoxes and Solstices The ecliptic is inclined to the celestial equator by $23^1/_2°$ because of the tilt of the Earth's axis of rotation. The ecliptic and the celestial equator intersect at two points called the equinoxes. The northernmost point on the ecliptic is called the summer solstice; the southernmost point is called the winter solstice.

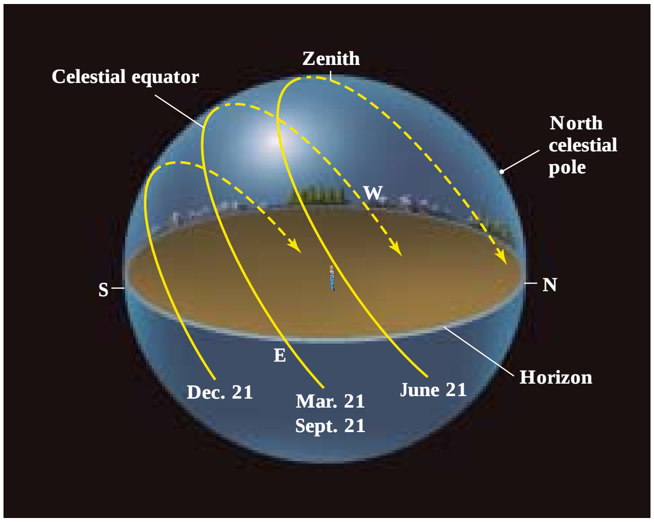



FIGURE 1-16 The Sun's Daily Path On the first day of spring and the first day of fall, as seen from middle latitudes in the northern hemisphere, the Sun rises precisely in the east and sets precisely in the west. During summer in the northern hemisphere, the Sun rises in the northeast and sets in the northwest. In winter, the Sun rises in the southeast and sets in the southwest.

rises directly in the east and sets directly in the west. Daytime and nighttime are of equal duration everywhere on Earth on those days only.

During the northern hemisphere's summer months, when the northern hemisphere is tilted toward the Sun, the Sun rises in the northeast and sets in the northwest. The Sun provides more than 12 hours of daylight in the northern hemisphere and passes high in the sky at noontime. At the summer solstice, the Sun is as far north as it gets, giving the greatest number of daylight hours to the northern hemisphere.

During the northern hemisphere's winter months, when the northern hemisphere is tilted away from the Sun, the Sun rises in the southeast. Daylight lasts for fewer than 12 hours, as the Sun skims low over the southern horizon and sets in the southwest. Night is longest in the northern hemisphere when the Sun is at the winter solstice.

People at different latitudes see the noontime Sun at different angles in the sky each day. The farther from the equator you are, the lower the Sun is in the sky at noon. The farther north you go, less of the Sun's heat and light energy are deposited (see Figure 1-14) and, therefore, the colder the land is. At latitudes above $66^1/_2°$ north latitude or below $66^1/_2°$ south latitude, the Sun does not rise at all during parts of their fall and winter months. During their spring and summer months, those same regions of the Earth have continuous sunlight for weeks or months, hence the name "Land of the Midnight Sun."

The Sun takes one year to complete a tri
ecliptic. Since there are about $365^1/_4$ days in a y
in a circle, the Sun appears to move along t
a rate of slightly less than 1° per day. The c
through which the Sun moves throughout the y
**zodiac** constellations. We cannot see the stars of these constellations when the Sun is among them, of course, but we can plot the Sun's path on the celestial sphere to determine through which constellations it moves. One traditionally learns that there are 12 zodiac constellations, which are used by astrologers. These 12 are based on constellation boundaries used in antiquity. Those boundaries have since been redefined by astronomers, and the Sun moves through 13 modern constellations throughout the year. (The thirteenth zodiac constellation is Ophiuchus, the Serpent Holder. The Sun passes through Ophiuchus from December 1 to December 19 each year.) Table 1-1 lists all the zodiac constellations and the dates the Sun passes through them.

## 1-7 Precession is a slow, circular motion of the Earth's axis of rotation

As noted above, the position of the Earth's axis of rotation changes slightly with respect to the celestial sphere (that is, it "points" in a slightly different direction) each year. This change in orientation is caused by gravitational forces from the Moon and Sun. Recall from Section I-2 that gravitation is the universal force of attraction between all matter. The Earth's rotation creates an "equatorial bulge"—our planet's diameter is about 43 km (27 mi) greater at the equator than from pole to pole.

TABLE 1-1 The 13 Constellations of the Zodiac

| Constellation | Dates of Sun's Passage Through |
|---|---|
| Pisces | March 13–April 20 |
| Aries | April 20–May 13 |
| Taurus | May 13–June 21 |
| Gemini | June 21–July 20 |
| Cancer | July 20–August 11 |
| Leo | August 11–September 18 |
| Virgo | September 18–November 1 |
| Libra | November 1–November 22 |
| Scorpius | November 22–December 1 |
| Ophiuchus | December 1–December 19 |
| Sagittarius | December 19–January 19 |
| Capricorn | January 19–February 18 |
| Aquarius | February 18–March 13 |

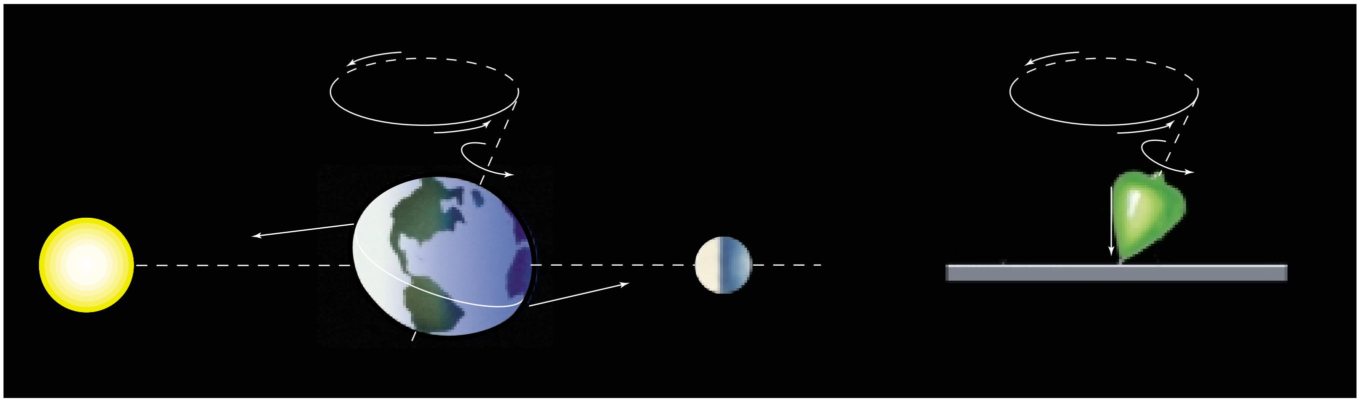


FIGURE 1-17 **Precession** The gravitational pulls of the Moon and the Sun on the Earth's equatorial bulge cause the Earth to precess. As the Earth precesses, its axis of rotation slowly traces out a circle in the sky. The situation is analogous to that of a spinning top. The top of the toy top shows the motion of Earth's north or south pole, while the point on which the top spins represents the center of the Earth. As the top spins, the Earth's gravitational pull causes the top's axis of rotation to move in a circle.

Because of the Earth's tilted axis of rotation, the Sun and Moon are usually not located directly over the Earth's equator. As a result, their gravitational attraction on the Earth tries to force the equatorial bulge to be as close to them as possible. However, the Earth does not respond to these forces from the Sun and Moon by straightening up perpendicular to them on its axis. Instead, it changes the direction in which its axis of rotation points on the celestial sphere—a motion called **precession.** This is exactly the same behavior that is exhibited by a spinning top (Figure 1-17). If the top were not spinning, gravity would pull it over on its side. But when it is spinning, the combined actions of gravity and rotation cause the top's axis of rotation to precess in a circular path. As with the toy top, the combined actions of gravity and rotation cause the Earth's axis to trace out a circle in the sky while remaining tilted about $23\frac{1}{2}°$ away from the perpendicular. In the mid-1990s, astronomers simulated the behavior of the Earth and discovered that without a large Moon, the Earth would not keep to a $23\frac{1}{2}°$ tilt but rather would change its tilt wildly, and even flip over!

The Earth's rate of precession is slow compared to human time scales. It takes about 26,000 years for the north celestial pole to trace out a complete circle around the sky, as shown in Figure 1-18. (The south celestial pole executes a similar circle in the southern sky.) At the present time, the Earth's north axis of rotation points within 1° of the star Polaris. In 3000 B.C., it was pointing near the star Thuban in the constellation of Draco (the Dragon). In A.D. 14,000, the pole star will be near Vega in Lyra.

WEB LINK 1.10

As the Earth's axis of rotation precesses, its equatorial plane also moves. Because the Earth's equatorial plane defines the location of the celestial equator in the sky, the celestial equator also precesses. Because the intersections of the celestial equator and the ecliptic define the equinoxes, these key locations in the sky also shift slowly from year to year. This entire phenomenon is often called the **precession of the equinoxes.** This change was discovered by the great Greek astronomer

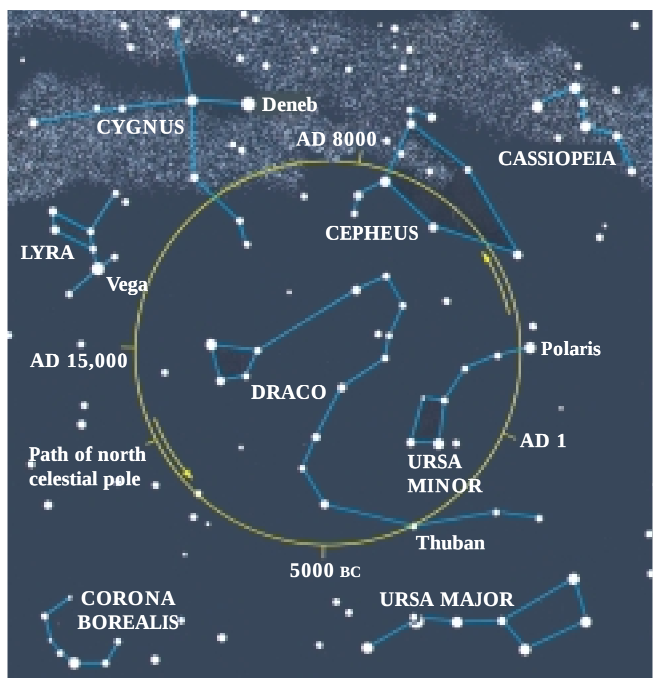



FIGURE 1-18 **The Path of the North Celestial Pole** As the Earth precesses, the north celestial pole slowly traces out a circle among the northern constellations. At the present time, the north celestial pole is near the moderately bright star Polaris, which serves as the pole star. The total precession period is about 26,000 years.

Hipparchus in the second century B.C. Today, the vernal equinox is located in the constellation Pisces (the Fishes). Two thousand years ago, it was located in Aries (the Ram). Around the year A.D. 2600, the vernal equinox will move into Aquarius (the Water Bearer).

## 1-8 The phases of the Moon originally inspired the concept of the month

The Moon's contribution to the Earth's precession causes changes that take millennia. Other lunar effects are noticeable every day. As the Moon orbits the Earth, we see different **lunar phases.** As with the Earth and other spherical bodies, the Sun illuminates half of the Moon at any time. The Moon's phase depends on how much of its sunlit hemisphere is exposed to our Earth-based view. When the Moon is closest to the Sun in the sky, its dark hemisphere faces the Earth. This phase, during which the Moon is at most a tiny crescent, is called the *new* Moon (Figure 1-19).

During the seven days following the new phase, more of the Moon's illuminated hemisphere becomes exposed to our view, resulting in a phase called the *waxing crescent* Moon. At the *first quarter* Moon, we see half of the illuminated hemisphere and half of the dark hemisphere. "Quarter Moon" refers to how far in its cycle the Moon has gone, rather than what fraction of the Moon appears lit by sunlight.

INTERACTIVE EXERCISE 1.2 ANIMATION 1.3

During the next week still more of the illuminated hemisphere can be seen from Earth, giving us the phase called the *waxing gibbous* Moon. When the Moon arrives on the opposite side of the Earth from the Sun, we see almost all of the fully illuminated hemisphere, which is called the *full* Moon. Over the following two weeks, we see less and less of the illuminated hemisphere as the Moon continues along its orbit. This movement produces the phases called the *waning gibbous* Moon, *third quarter* Moon, and the *waning crescent* Moon.

The Moon completes a full cycle of phases in 29½ days. 5
Thus, the side of the Moon facing away from Earth, its *far side*, is not always dark, and so the Moon's far side is not necessarily its "dark side."

Figure 1-19 shows the Moon at various positions in its 6
orbit. Remember that the bright side of the Moon is on the right (west) side of the waxing Moon, while the bright side is on the left (east) side of the waning Moon. When looking at the Moon through a telescope, the best place to see details is where the shadows are longest. This occurs at the boundary between the bright and dark regions, called the **terminator.**

Figure 1-19 also shows local time around the globe, from noon, when the Sun is highest in the sky, to midnight, when it is on the opposite side of the Earth. These time markings can be used to correlate the phase and position of the Moon with the time of day. For example, at first quarter, the Moon is 90° east of the Sun in the sky; hence, moonrise occurs approxi-


### MOVIE MISCONCEPTIONS

*The Mummy Returns* (Universal Pictures, 2001)
(The Everette Collection)

**The movie *The Mummy Returns* is set in 1935, where our heroes Rick and Evelyn O'Connell are married, raising their nine-year-old son, Alex. In the movie, Alex puts on an ancient Egyptian bracelet which, he then learns, must be carried into a pyramid within one week or *awful things* will happen. At the same time, the mummy of the Egyptian high priest Imhotep, the mummy of the film's title, is being brought back to life. The reincarnation of his former mistress, Anck-Su-Namun is waiting for him and, projected mystically and momentarily to the pyramid, they kiss under a thin crescent moon. (This scene might be construed as a flashback to their former lives, but for the purposes of this question, we will assume it occurs at the time of the rest of the movie's events.) The boy is then kidnapped by the mummy's minions and whisked on a journey to the temple. He is followed by his father and mother, among others, traveling part of the trip in a balloon that is shown crossing the full Moon. The boy gets into the temple on time and the rest of the movie unfolds. What is wrong with the astronomy in the movie, as described above?**

**(Answers appear at the end of the book.)**

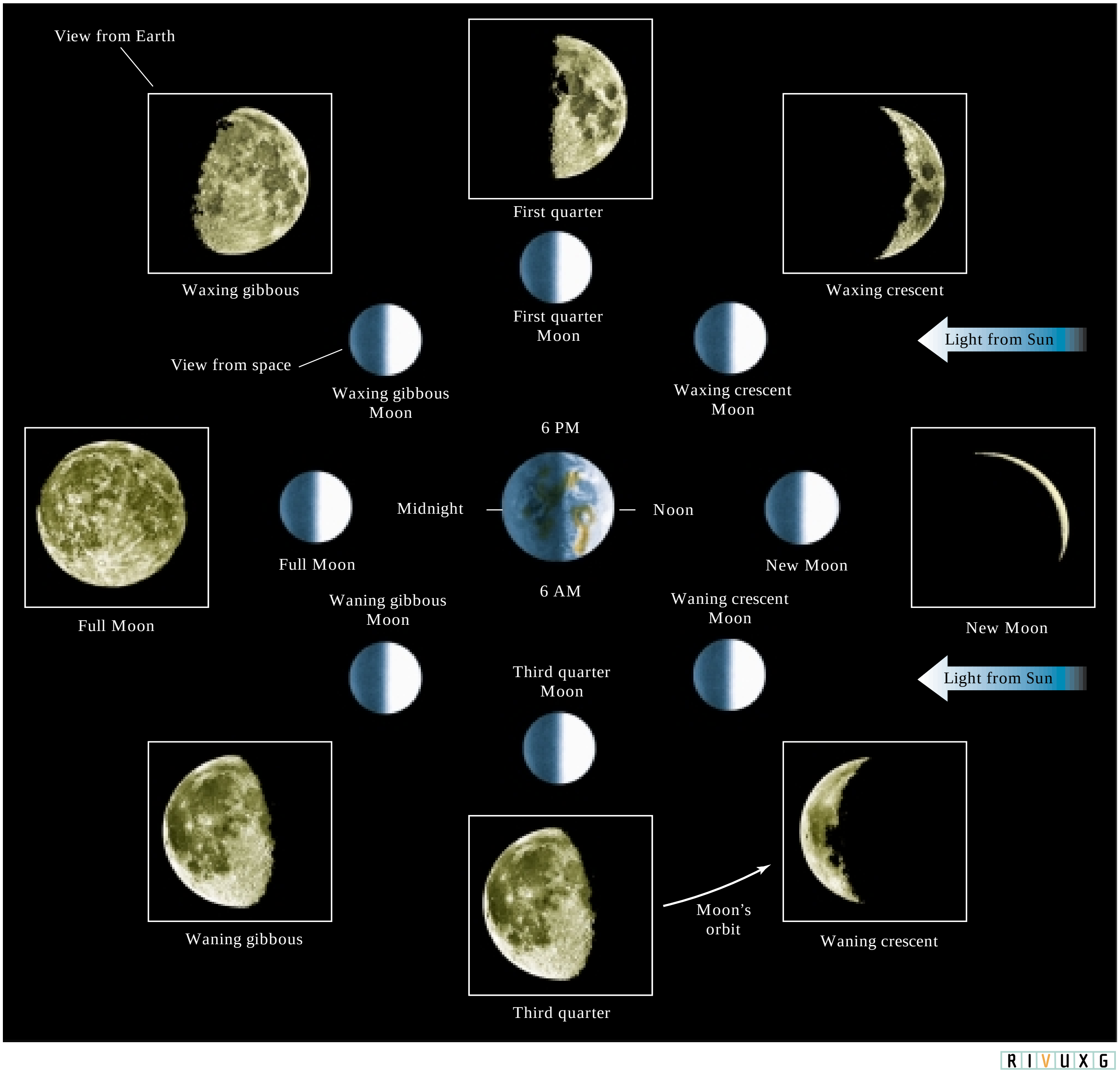



**FIGURE 1-19** **The Phases of the Moon** The diagram shows the Moon at eight locations on its orbit as viewed from far above the Earth's north pole. The corresponding photographs show the resulting lunar phases as seen from Earth. The waning and third quarter photographs look backwards, but they are correctly oriented as seen from Earth. Light from the Sun illuminates one-half of the Moon at all times, while the other half is dark. It takes about 29½ days for the Moon to go through all its phases. (Yerkes Observatory & Lick Observatory)

mately at noon. At full Moon, the Moon is opposite the Sun in the sky; thus, moonrise occurs at sunset. Using this information, you can see that the Moon is visible during the daytime (Figure 1-20) for a part of most days of the year.

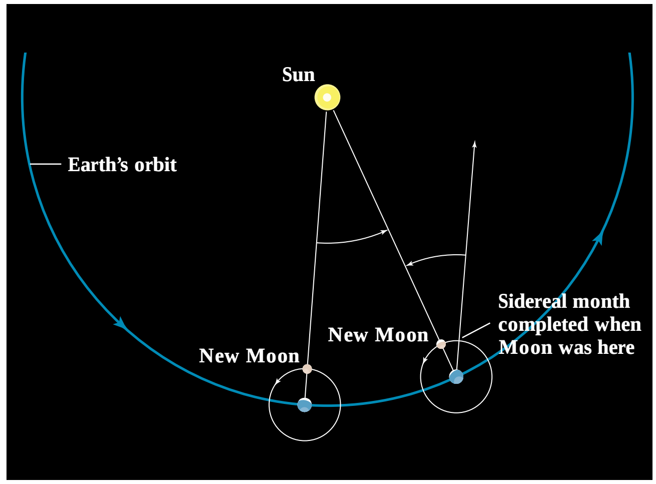
Since the dawn of civilization, people have sought accurate timekeeping systems. Ancient Egyptians wanted to know when the Nile would flood, and farmers everywhere needed to know when to plant crops. Migratory tribes wanted to know when the weather would change. Religious leaders scheduled observances in accordance with celestial events. Thus, astronomers have traditionally been responsible for telling time. Indeed, of the four ways in which time cycles are set, three are astronomical in origin: Time is determined by the positions of the Moon, Sun, or stars or, in our own age, by technological means, such as atomic clocks.

The approximately four weeks that the Moon takes to complete one cycle of its phases inspired our ancestors to invent the concept of a month. Astronomers find it useful to define two types of months, depending on whether the Moon's motion is measured relative to the stars or to the Sun. Neither type corresponds exactly to the months of our usual calendar, which have different lengths.

The **sidereal month** is the time it takes the Moon to complete one full orbit of 360° around the Earth (Figure 1-21). This is also the time it takes the Moon to start at one place on the celestial sphere and return to exactly the same place again. Indeed, sidereal motion of any astronomical body is motion measured with respect to the distant stars. This true orbital period for the Moon is approximately 27.3 days. The **synodic month,** or **lunar month,** is the time it takes the Moon to complete one 29½-day cycle of phases (that is, from new Moon to new Moon or from full Moon to full Moon) and thus is measured with respect to the Sun rather than the distant stars.

The synodic month is longer than the sidereal month, because the Earth is orbiting the Sun while the Moon goes through its phases. As shown in Figure 1-21, the Moon must travel *more* than 360° along its orbit to complete a cycle of phases (for example, from one new Moon to the next), which takes about 2.2 days longer than the sidereal month.

Both the sidereal month and synodic month vary somewhat, because the gravitational pull of the Sun on the Moon affects the Moon's speed as it orbits the Earth. The sidereal month can vary by as much as 7 hours, while the synodic month can vary by as much as 12 hours.




ANIMATION 1.4

FIGURE 1-21 The Sidereal and Synodic Months The sidereal month is the time it takes the Moon to complete one revolution with respect to the background stars. However, because the Earth is constantly moving in its orbit about the Sun, the Moon must travel through more than 360° to get from one new Moon to the next. The synodic month is the time between consecutive new moons or consecutive full moons. Thus, the synodic month is slightly longer than the sidereal month.

R I V U X G

FIGURE 1-20 The Moon during the Day The Moon is visible at some time during daylight hours virtually every day. The time of day or night it is up in our sky depends on its phase. (Art Wolfe)

The terms *synodic* and *sidereal* are also used in discussing the motion of the other bodies in the solar system. The synodic period of a planet is the time between consecutive straight alignments between the Sun, Earth, and that planet (during which time the planet also goes through a cycle of phases, as seen from the Earth). On the other hand, any orbit measured with respect to the distant stars is called "sidereal," including orbits of the planets around the Sun, as well as orbits of moons around their planets. The Earth's sidereal year is 365.2564 days. The difference between the sidereal year and the tropical year is due primarily to the Earth's precession (see Section 1-7).

## ECLIPSES

### 1-9 Eclipses occur only when the Moon crosses the ecliptic during the new or full phase

Eclipses are among the most spectacular natural phenomena. During a **lunar eclipse,** the brilliant full Moon often darkens to a deep red, while during a solar eclipse, broad daylight is transformed into an eerie twilight, as the Sun seems to be blotted from the sky. A lunar eclipse occurs when the Moon passes through the Earth's shadow. This can happen only when the Sun, Earth, and Moon are in a straight line at full Moon. A **solar eclipse** occurs when the Moon's shadow moves across the Earth's surface. As seen from Earth, the Moon moves in front of the Sun. This can happen only when the Sun, Moon, and Earth are aligned at new Moon.

At first glance, it would seem that eclipses should happen at every new and full Moon, but, in fact, they occur much less often. Eclipses occur infrequently because the Moon's orbit is tilted 5° out of the ecliptic, as shown in Figure 1-22. Because of this tilt, the new Moon and full Moon usually occur when the Moon is either above or below the plane of the Earth's orbit. In such positions, a perfect alignment between the Sun, Moon, and Earth is not possible and an eclipse cannot occur.

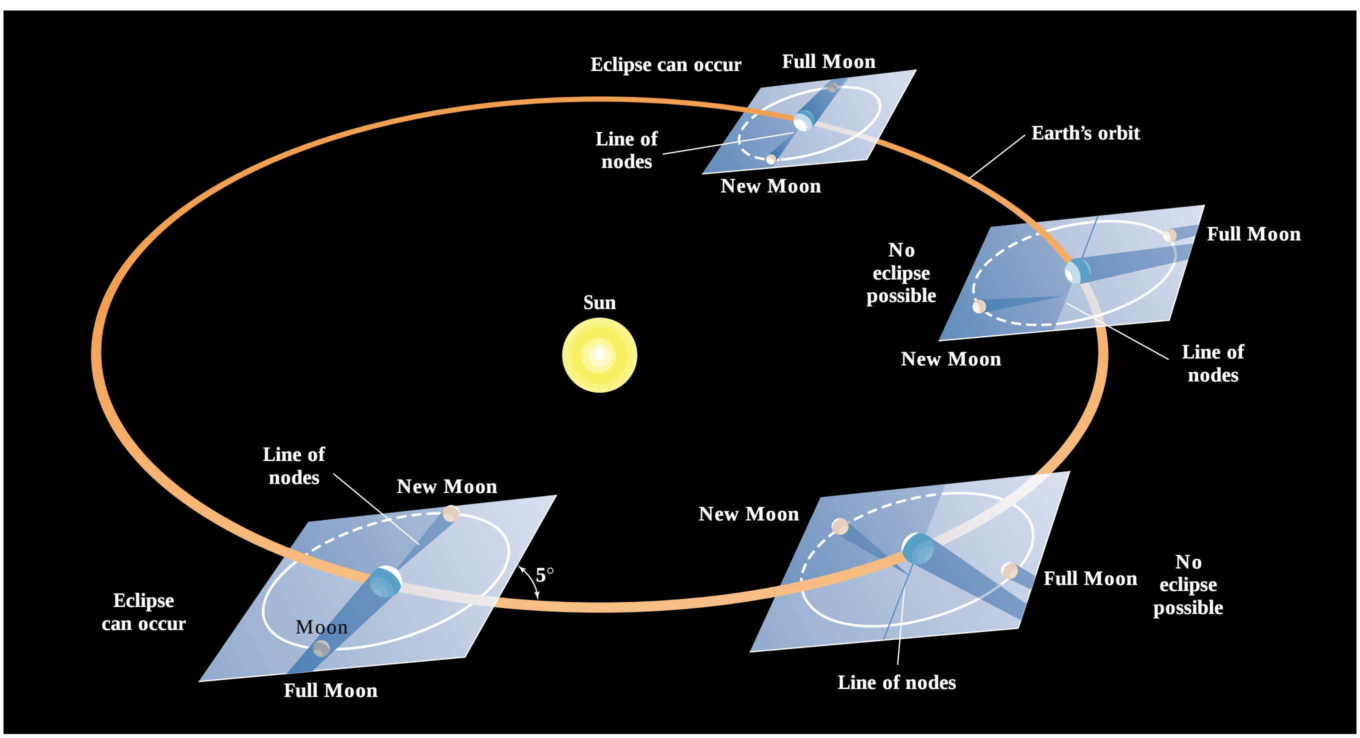
When the Moon crosses the plane of the ecliptic during its new or full phase, an eclipse takes place. The Moon crosses the ecliptic at what is called the **line of nodes** (see Figure 1-22). By calculating the number of times a new Moon takes place on the line of nodes, we find that at least two and no more than five solar eclipses occur each year. Lunar eclipses occur just about as frequently as solar eclipses, but the maximum number of eclipses (solar plus lunar) possible in a year is seven.

MORE TO KNOW 1.3 Maximum Number of Eclipses Annually

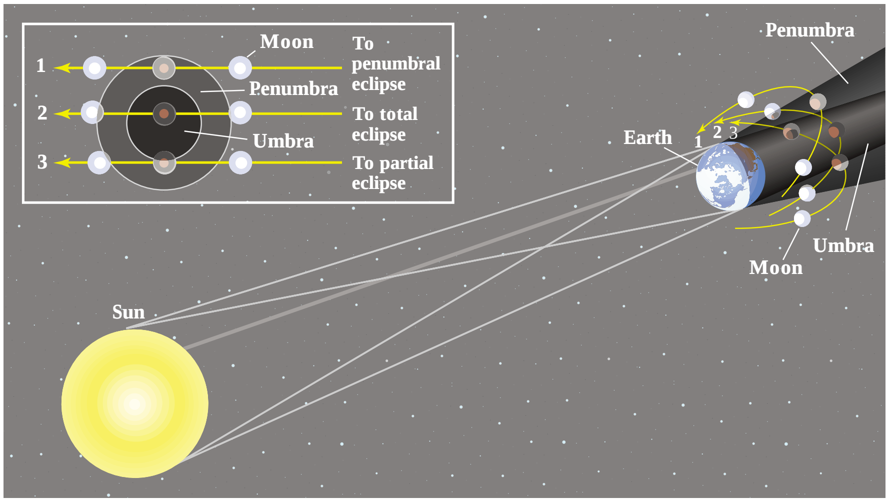
## 1-10 There are three types of lunar eclipse

The Earth's shadow has two distinct parts, as shown in Figure 1-23. The **umbra** is the part of the shadow where all direct sunlight is blocked by the Earth. The **penumbra** of the shadow is where the Earth blocks only some of the sunlight. Depending on how the Moon travels through the Earth's shadow, three kinds of lunar eclipses may occur. A **penumbral eclipse,** when the Moon passes through only the Earth's penumbra, is easy to miss. The Moon still looks full, just a little dimmer than usual or even reddish in color.

When only part of the lunar surface passes through the umbra, a bite seems to be taken out of the Moon, and we see a **partial eclipse.** When the Moon travels completely into the umbra, as sketched in Figure 1-23, we see a **total eclipse** of the Moon. Totality is the time when the entire Moon is in




INTERACTIVE EXERCISE 1.3 **FIGURE 1-22 Conditions for Eclipses** The Moon must be very nearly on the ecliptic at new Moon for a solar eclipse to occur. A lunar eclipse occurs only if the Moon is very nearly on the ecliptic at full Moon. When new Moon or full Moon phases occur away from the ecliptic, no eclipse is seen, because the Moon and the Earth do not pass through each other's shadows.




INTERACTIVE EXERCISE 1.4

**FIGURE 1-23** Three Types of Lunar Eclipses People on the nighttime side of the Earth see a lunar eclipse when the Moon moves through the Earth's shadow. The umbra is the darkest part of the shadow. In the penumbra, only part of the Sun is covered by the Earth. The inset shows the various lunar eclipses that occur, depending on the Moon's path through the Earth's shadow.

the Earth's umbra. Eclipses with the maximum duration of totality, lasting for up to 1 hour 47 minutes, occur when the Moon is closest to the Earth and travels directly through the center of the umbra. Table 1-2 lists all the total and partial lunar eclipses from late 2002 through 2006.

Even during a total eclipse, the Moon does not completely disappear. A small amount of sunlight passing through the Earth's atmosphere is bent into the Earth's umbra. The light deflected into the umbra is primarily red and orange, and thus the darkened Moon glows faintly in rust-colored hues during totality, as shown in Figure 1-24. At sunrise and sunset the Sun appears red or orange for the same reason, specifically, because at those times red and orange light are deflected from the Sun toward you. Other colors, especially violet, blue, and green, are actually deflected by the air so much more than red, orange, and yellow that the former colors from the Sun do not enter the Earth's umbra or reach us at sunrise and sunset.

Lunar eclipses are perfectly safe to watch with the naked eye. However, solar eclipses are *never* safe to view without suitable eye protection. *Viewing the Sun directly at any time without an approved filter causes permanent eye damage.*

## 1-11 There are also three types of solar eclipse

Because of their different distances from Earth, the Sun and the Moon have nearly the same angular diameter as seen from Earth—about $^1/_2°$. When the Moon completely covers the Sun, the result is a *total solar eclipse.* You must be at a location within the Moon's umbra to see a total solar eclipse.

WEB LINK 1.11

**TABLE 1-2** Lunar Eclipses, 2002–2006

| Date | Visible from | Type | Duration of totality (h:min) |
|---|---|---|---|
| 2002 November 20 | Americas, Europe, Africa, eastern Asia | Penumbral | |
| 2003 May 16 | Americas, Europe, Africa | Total | 0:53 |
| 2003 Nov 9 | Americas, Europe, Africa, central Asia | Total | 0:24 |
| 2004 May 4 | South America, Europe, Africa, Asia, Australia | Total | 1:16 |
| 2004 October 8 | Americas, Europe, Africa, central Asia | Total | 1:21 |
| 2005 April 24 | Americas, eastern Asia, Australia | Penumbral | |
| 2005 October 17 | North America, Asia, Australia | Partial | |
| 2006 March 14 | Americas, Europe, Africa, Asia | Penumbral | |
| 2006 September 7 | Europe, Africa, Asia, Australia | Partial | |

R I V U X G

FIGURE 1-24 **A Total Eclipse of the Moon** Notice the distinctly reddish color of the Moon in this photograph, taken by an amateur astronomer during the lunar eclipse of September 6, 1979. (M. Harms)

During those few precious moments, hot gases (the **solar corona**) surrounding the Sun can be observed and photographed (Figure 1-25). Astronomers can then learn more about the Sun's temperature, chemistry, and atmospheric activity. You can see in Figure 1-26 that only the tip of the Moon's umbra ever reaches the Earth's surface. As the Earth turns and the Moon orbits, the tip traces an **eclipse path** across the Earth's surface. Only people within this path are treated to the spectacle of a total solar eclipse. Figure 1-26 shows the dark spot produced by the Moon's umbra on the Earth's surface during a total solar eclipse.

The Earth's rotation and the orbital motion of the Moon cause the umbra to race along the eclipse path at speeds in excess of 1700 km/h (1050 mph). Totality never lasts for more than 7 1/2 minutes at any one location on the eclipse path, and it usually lasts for only a few moments.

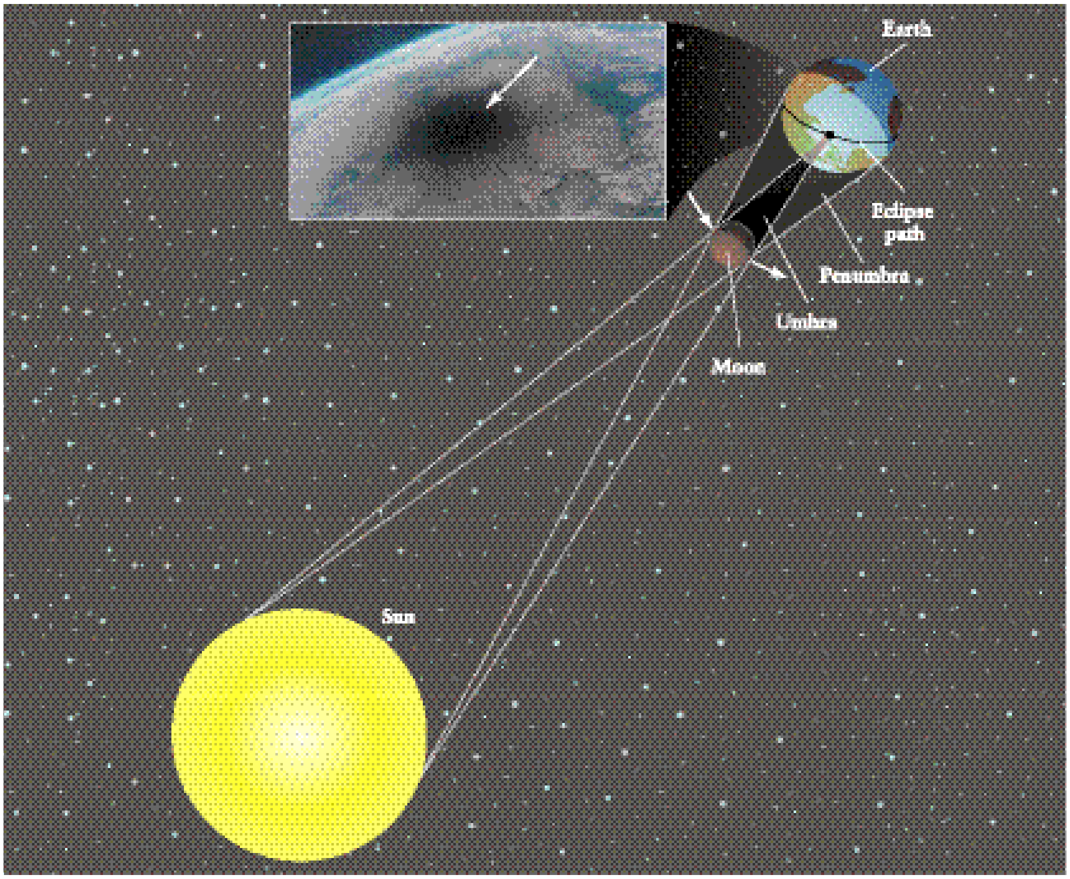
The Moon's umbra is also surrounded by a penumbra. During a solar eclipse, the Moon's penumbra extends over a large portion of the Earth's surface. When only the penumbra sweeps across the Earth's surface, the Sun is only partly covered by the Moon. This circumstance results in a *partial eclipse of the Sun*. Similarly, people in the penumbra of a total eclipse see a partial eclipse.

The Moon's orbit around the Earth is not quite a perfect circle. The distance between the Earth and the Moon, which averages 384,400 km (238,900 mi), varies by a few percent as the Moon goes around the Earth. The width of the eclipse path depends primarily on the Earth-Moon distance during an eclipse. The eclipse path is widest—up to 270 km (170 mi)—when the Moon happens to be at the point in its orbit nearest the Earth. Usually, however, the path is much narrower.

If a solar eclipse occurs when the Moon is farthest from the Earth, then the Moon's umbra falls short of the Earth and

R I V U X G

FIGURE 1-25 **A Total Eclipse of the Sun** During a total solar eclipse, the Moon completely covers the Sun's disk, and the solar corona can be photographed. This halo of hot gases extends for millions of kilometers into space. This gorgeous image is a composite of several taken in Chisamba, Zambia, during the June 21, 2001 solar eclipse. (F. Espenak)




R I V U X G

**FIGURE 1-26** **The Geometry of a Total Solar Eclipse** During a total solar eclipse, the tip of the Moon's umbra traces an eclipse path across the Earth's surface. People inside the eclipse path see a total solar eclipse, whereas people inside the penumbra see only a partial eclipse. The photograph in this figure shows the Moon's shadow on the Earth. It was taken from the *Mir* space station during the August 11, 1999 total solar eclipse. The Moon's umbra appears as a dark spot on the eastern coast of the United States. (Jean-Pierre Haigneré, Centre National d'Etudes Spatiales, France/GSFS)

no one sees a total eclipse. From the Earth's surface, the Moon then appears too small to cover the Sun completely, and a thin ring or "annulus" of light is seen around the edge of the Moon at mid-eclipse. This type of eclipse is called an **annular eclipse** (Figure 1-27). The length of the Moon's umbra is nearly 5000 km (3100 mi) shorter than the average distance between the Moon and the Earth's surface. Thus, the Moon's shadow often fails to reach the Earth, making annular eclipses more common than total eclipses. Table 1-3 lists all the total, partial, and annular solar eclipses from late 2002 through 2006.

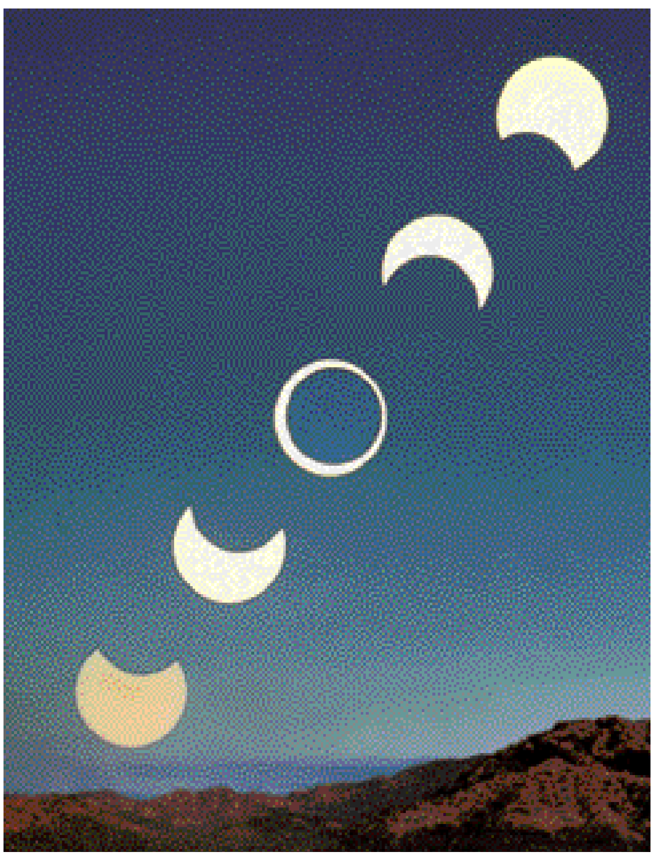
A total solar eclipse is a dramatic event. The sky begins to darken, the air temperature falls, and the winds increase as the Moon's umbra races toward you. All nature responds: Birds go to roost, flowers close their petals, and crickets begin to chirp as if evening had arrived. As totality approaches, the landscape is bathed in shimmering bands of light and dark as the last few rays of sunlight peek out from behind the edge of the Moon. Finally, the corona blazes forth in a star-studded daytime sky. It is an awesome sight but should only be viewed through a suitable protective filter.

## 1-12 Frontiers yet to be discovered

Geologists have discovered a variety of cycles of global temperature change that have occurred over the history of the Earth. Indeed, in the 1990s geologists discovered that much of the Earth once suffered a global freezing. These changes occur over tens of thousands of years, hundreds of thousands of years, and possibly longer cycles. Some of the causes of these changes have yet to be discovered. Even today the Earth's global climate is changing over the years. All the causes of this change are not yet known. For example, are our activities the only cause of global warming or

**TABLE 1-3 Solar Eclipses, 2002–2006**

| Date | Type | Area | Notes |
|---|---|---|---|
| 2002 December 4 | Total | southern Africa, Australia, Indonesia | Maximum length 2:04 |
| 2003 May 31 | Annular | Europe, Asia, northwest North America | Maximum length 3:37 |
| 2003 November 23 | Total | Australia, southern South America | Maximum length 1:57 |
| 2004 April 19 | Partial | southern Africa | |
| 2004 October 14 | Partial | northeast Asia, Hawaii, Alaska | |
| 2005 April 8 | Total | New Zealand, North and South America | Maximum length 0:42 |
| 2005 October 3 | Annular | Europe, Africa, southern Asia | Maximum length 4:32 |
| 2006 March 29 | Total | Africa, Europe, western Asia | Maximum length 4:07 |
| 2006 September 22 | Annular | South America, western Africa | Maximum length 7:09 |



R I V U X G

**FIGURE 1-27** **An Annular Eclipse of the Sun** This composite of five exposures taken at sunrise in Costa Rica shows the progress of an annular eclipse of the Sun that occurred on December 24, 1974. Note that at mid-eclipse the edge of the Sun is visible around the Moon. (Dennis Di Cicco)

are there long-term seasonal changes that affect it and, if so, how? Another question yet to be answered is how the Earth got its 23$\frac{1}{2}$° tilt.

Further Reading on These Topics

## WHAT DID YOU KNOW?

1 *Is the North Star—Polaris—the brightest star in the night sky?* Polaris is a star of medium brightness compared with other stars visible to the naked eye.

2 *Do astronomers regard constellations as simply the familiar patterns of stars in the sky first identified by ancient stargazers?* Astronomers sometimes use the common definition of a constellation as a pattern of stars. Formally, however, a constellation is an entire region of the celestial sphere and all the stars and other objects in it. Viewed from Earth, the entire sky is covered by 88 different-sized constellations. If there is any room for confusion, astronomers refer to the patterns as asterisms.

3 *What causes the seasons?* The tilt of the Earth's rotation axis with respect to the ecliptic causes the seasons. They are not caused by the changing distance from the Earth to the Sun that results from the shape of Earth's orbit.

4 *How many zodiac constellations are there?* There are 13 zodiac constellations, the lesser-known one being Ophiuchus.

5 *Does the Moon have a dark side that we never see from Earth?* Half of the Moon is always dark. Whenever we

see less than a full Moon, we are seeing part of the Moon's dark side. So, the dark side of the Moon is not the same as the far side of the Moon, which we never see from Earth.

6 *Is the Moon ever visible during the daytin* Moon is visible at some time during dayli almost every day of the year. Different ph visible during different times of the day.

## KEY WORDS

angle, 19
angular diameter (angular size), 19
annular eclipse, 35
arc angle, 19
autumnal equinox, 26
celestial equator, 18
celestial pole, 18
celestial sphere, 18
circumpolar stars, 20
constellation, 18
declination, 18
degree (°), 19
diurnal motion, 20
eclipse path, 34
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lunar phases, 29
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precession of the equinoxes, 28
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solar eclipse, 32
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synodic month (lunar month), 31
terminator, 29
time zone, 21
total eclipse, 32
umbra, 32
vernal equinox, 26
winter solstice, 26
zenith, 20
zodiac, 27

## KEY IDEAS

### Patterns of Stars

- The surface of the celestial sphere is divided into 88 unequal regions called constellations.

### Earthly Cycles

- The celestial sphere appears to revolve around the Earth once in each day-night cycle. In fact, it is the Earth's rotation that causes that apparent motion.
- The poles and equator of the celestial sphere are determined by extending the axis of rotation and the equatorial plane of the Earth out onto the celestial sphere.
- Earth's axis of rotation is tilted at an angle of $23\frac{1}{2}°$ from the perpendicular to the plane of the Earth's orbit. This tilt causes the seasons.
- Equinoxes and solstices are significant points along the Earth's orbit that are determined by the relationship between the Sun's path on the celestial sphere (the ecliptic) and the celestial equator.
- The Earth's axis of rotation slowly changes direction relative to the stars over thousands of years, a phenomenon called precession. Precession is caused by the gravitational pull of the Sun and Moon on the Earth's equatorial bulge.
- The length of the day is based upon the average motion of the Sun along the celestial equator, which produces the 24-hour day upon which our clocks are based.
- The phases of the Moon are caused by the relative positions of the Earth, Moon, and Sun. The Moon completes one cycle of phases in a synodic month, which averages $29\frac{1}{2}$ days.
- The Moon completes one orbit around the Earth with respect to the stars in a sidereal month, which averages 27.3 days.

### Eclipses

- The shadow of an object has two parts: the umbra, where direct light from the source is completely blocked; and the penumbra, where the light source is only partially obscured.
- A lunar eclipse occurs when the Moon moves through the Earth's shadow. During a lunar eclipse, the Sun, Earth, and Moon are in alignment, and the Moon is in the plane of the ecliptic.
- A solar eclipse occurs when a strip of the Earth passes through the Moon's shadow. During a solar eclipse, the Sun, Earth, and Moon are in alignment, and the Moon is in the plane of the ecliptic.
- Depending on the relative positions of the Sun, Moon, and Earth, lunar eclipses may be penumbral, partial, or total, and solar eclipses may be annular, partial, or total.

## REVIEW QUESTIONS

1 How are constellations useful to astronomers?

2 What is the celestial sphere, and why is this ancient concept still useful today?

3 What is the celestial equator, and how is it related to the Earth's equator? How are the north and south celestial poles related to the Earth's axis of rotation?

4 What is the ecliptic, and why is it tilted with respect to the celestial equator?

5 By about how many degrees does the Sun move along the ecliptic each day?

6 Through how many constellations does the Sun move every day?

7 Through how many constellations does the Sun move every year?

8 Why does the tilt of the Earth's axis relative to its orbit cause the seasons as the Earth revolves around the Sun? Draw a diagram to illustrate your answer.

9 What are the vernal and autumnal equinoxes? What are the summer and winter solstices? How are these four points related to the ecliptic and the celestial equator?

10 What is precession, and how does it affect our view of the heavens?

11 How does the daily path of the Sun across the sky change with the seasons?

12 Why is it warmer in the summer than in the winter?

13 Why is it convenient to divide the Earth into time zones?

14 Why does the Moon exhibit phases?

15 What is the difference between a sidereal month and a synodic month? Which is longer? Why?

16 What is the line of nodes, and how is it related to solar and lunar eclipses?

17 What is the difference between the umbra and the penumbra of a shadow?

18 What is a penumbral eclipse of the Moon? Why is it easy to overlook such an eclipse?

19 Which type of eclipse—lunar or solar—have most people seen? Why?

20 How is an annular eclipse of the Sun different from a total eclipse of the Sun? What causes this difference?

21 When is the next leap year?

22 At which phase(s) of the Moon does a solar eclipse occur? A lunar eclipse?

23 Is it safe to watch a solar eclipse without eye protection? A lunar eclipse?

24 During what phase is the Moon least visible in the daytime?

## ADVANCED QUESTIONS

The answers to all computational problems, which are preceded by an asterisk (*), appear at the end of the book.

25 During what phase(s) does the Moon rise after sunrise and before sunset? After sunset and before sunrise? At sunset? At sunrise?

26 Why can't a person in Australia use the Big Dipper to find north?

27 Are there any stars in the sky that are not members of a constellation?

28 At what places on Earth is Polaris seen on the horizon?

29 Where do you have to be on the Earth to see the Sun at your zenith? If you stay at one such location for a full year, on how many days will the Sun pass through the zenith?

30 Where do you have to be on Earth to see the south celestial pole at your zenith? What is the maximum possible elevation (angle) of the Sun above the horizon at that location? On what date is this maximum elevation achieved?

31 Where on the horizon does the Sun rise at the time of the vernal equinox?

32 Consult a star map of the southern hemisphere and determine which, if any, of the bright southern stars could someday become south celestial pole stars.

33 Are there stars in the sky that never set where you live? Are there stars that never rise where you live? Does your answer depend on your location on Earth? Why or why not?

34 Using a diagram, demonstrate that your latitude on Earth is equal to the altitude of the north celestial pole above your northern horizon.

35 Using a star map, determine which bright stars, if any, could someday mark the location of the vernal equinox. Give the approximate years when this should happen.

36 What is the phase of the Moon if it (a) rises at 3 A.M.? (b) sets at 9 P.M.? At what time does (c) the full Moon set? (d) the first quarter Moon rise?

37 What is the phase of the Moon if, on the first day of spring, the Moon is located at the position of (a) the vernal equinox, (b) the summer solstice, (c) the autumnal equinox, (d) the winter solstice?

*38 How many more sidereal months than synodic months are there in a year? Why?

39 How do we know that the phases of the Moon are not due to the Moon moving in the Earth's shadow?

40 Do the paths of total solar eclipses fall more frequently on oceans or on land? Explain.

41 Can one ever observe an annular eclipse of the Moon? Why or why not?

42 Which of the five images of the Sun is the first and which is the last in the sequence shown in the photograph for Figure 1-27? Justify your answer.

43 During a lunar eclipse, does the Moon enter the Earth's shadow from the east or the west? Explain your answer.

44 Do we see all of the Moon's surface from *Hint:* Carefully examine the photographs in Fi

45 Explain why the waning gibbous, third qua waning crescent photographs in Figure 1-19 are oriented as seen from Earth.

46 Why is a small crescent of light often observed on the Moon when it is exactly in the new phase?

47 Make a drawing of an annular solar eclipse as seen from space. Be sure to make clear how it differs from a total solar eclipse.

*48 Assuming that the Sun makes an angle of $1/2°$ in our sky and is at a distance of $1.496 \times 10^{11}$ m, what is the Sun's diameter? Divide this by 2 to find the Sun's radius and explain why this result is slightly different from the value given in Appendix Table A-6.

49 How long was the exposure for the photograph of circumpolar star trails that opens this chapter?

50 Determine which stars whose paths are shown in the photo that opens this chapter are *not* circumpolar. An easy way to write the answer is in terms of distance on the photograph from the location of the south celestial pole.

## DISCUSSION QUESTIONS

51 Examine a list of the 88 constellations. Are there any constellations whose names obviously date from modern times? Where are these constellations located? Why do they not have ancient names?

52 In his novel *King Solomon's Mines,* H. Rider Haggard described a total solar eclipse that was seen in both South Africa and the British Isles. Is such an eclipse possible? Why or why not?

53 Describe how a lunar eclipse would look if the Earth had no atmosphere.

54 Examine a listing of total solar eclipses over the next several decades. What are the chances that you might be able to travel to one of the eclipse paths? Do you think you might go through your entire life without ever seeing a total eclipse of the Sun?

## WHAT IF ...

55 The Moon moved about the Earth in an orbit perpendicular to the plane of the Earth's orbit? What would the cycle of lunar phases be? Would solar and lunar eclipses be possible under these circumstances?

56 The Earth's axis of rotation were tilted at a different angle? What would the seasons be like where you are now if the axis of rotation is (a) 0° and (b) 45° to its orbital plane. What would be different about the seasons and the day-night cycle if you lived at one of the Earth's poles?

57 You watched the Earth from the Moon? What would you see for Earth's (a) daily motion, (b) motion along the celestial sphere, and (c) cycle of phases.

58 The Moon didn't rotate? Describe how its surface *features* would appear from the Earth—that is, would we see all sides of it over time? Why or why not? (Ignore the change in phase when discussing its appearance.) *Carefully* study the photographs in Figure 1-19 and state whether the same features are visible at all times or whether we see different features over time. (Again, ignore the phases.) What can you conclude about whether the Moon actually rotates?

## WEB/CD-ROM QUESTIONS

*59 Work through the AIMM (Active Integrated Media Module) called "Small-Angle Toolbox" in Chapter 1 of the *Discovering the Universe* CD-ROM or Web site. Use it to determine the diameters in kilometers of the Sun, Saturn, and Pluto given the following distances and angular sizes:

| Object | Distance (km) | Angular size (″) |
|---|---|---|
| Sun | $1.5 \times 10^8$ | 1800 |
| Saturn | $1.5 \times 10^9$ | 16.5 |
| Pluto | $6.3 \times 10^9$ | 0.06 |

60 Search the Web for information about the Great Nebula of Orion (also called the Orion nebula, see Figure 1-1). Can the Great Nebula be seen with the naked eye? Does it exist alone in space or is it part of a larger system of interstellar material? What has been learned by examining the Great Nebula with telescopes sensitive to infrared light?

61 Search the Web for information about the national flags of Australia, New Zealand, and Brazil, and the state flag of Alaska. What stars are depicted on these flags? Explain any similarities or differences among these flags.

62 Search the Web for the English meaning of the Japanese word *Subaru*. Make a drawing of the Subaru car's emblem and explain it.

63 Use the U.S. Naval Observatory's Web site to determine the times of sunset and sunrise on (a) your birthday and (b) the date this assignment is due. Are the times the same? Explain why or why not.

64 Search the Web for information about the next total solar eclipse. Through which major cities, if any, does the path of totality pass? What is the maximum duration of totality? Find a location where this maximum duration is observed. Will the eclipse be visible (even as a partial eclipse) from your present location?

65 Search the Web for information about the next total lunar eclipse. Will the total phase of the eclipse be visible from your present location? If not, will the penumbral phase be visible? Draw a picture of the Sun, Earth, and Moon at totality and indicate your location on the drawing of the Earth.

66 Access the animation "The Moon's Phases" in Chapter 1 of the *Discovering the Universe* Web site or CD-ROM. This shows the Earth-Moon system as seen from a vantage point above the Earth's north pole. (a) Describe where you would be on the diagram if you are on the equator and the time were 6:00 P.M. (b) If it were 6:00 P.M. and you were standing on the Earth's equator, would a third-quarter Moon be visible? Why or why not? If it would be visible, describe its appearance.

## OBSERVING PROJECTS

67 On a clear, cloud-free night, use the star charts within the covers of this book to see how many constellations of the zodiac you can identify. Which ones are easy to find? Which are difficult?

68 Using *Starry Night Backyard*™ with all pattern lines off, see if you can identify the zodiac constellations that are visible in the sky this evening. Set the time to sometime after sunset and turn off the sky motion by clicking on the square to the left of the timestep indicator. Then "grab" the sky and move around until you recognize some constellations. Use the star charts within the covers of this book for guidance, if necessary. If you still have difficulty finding zodiac constellations, click on *Guides* and then on *The Ecliptic* to highlight the part of the sky in which the zodiac is located. If you still have trouble, go to *Constellations* and click on *Astronomical* to see the asterisms. If you need even more help, go to *Constellations* again and click on *Auto Identify*. Then as you move the little hand over a constellation, its name and classical image will appear. Watch out for planets, which are also found in the zodiac—you may have to ignore one or more of these bright objects in picking out the constellation patterns. Moving the hand icon over an object will tell you what it is. Return to *Home* (assuming it is daylight when you do this), switch off daylight and determine which zodiac constellation the Sun is passing through today.

69 Use *Starry Night Backyard*™ to observe the diurnal motion of the sky. (a) First set *Starry Night Backyard*™ to display the sky as seen from where you live. Select *Set Home Location…* in the *Go* menu and click on the *Lookup* button to find your city or town. Then, using the hand cursor, center your field of view on the northern horizon (if you live in the northern hemisphere) or southern horizon (if you live in the southern hemisphere). In the Control Panel on the top of the main window, set the timestep to 3 minutes and click on the *Forward* button. To see the stars during the daytime, turn off daylight (select *Daylight* in the *Sky* menu). Do the stars appear to revolve clockwise or

counterclockwise? Explain this in terms of the Earth's rotation. Are any of the stars circumpolar? (b) Recenter your field of view on the southern horizon (if you live in the northern hemisphere) or the northern horizon (if you live in the southern hemisphere). Describe what you see. Are any of these stars circumpolar?

70 Use the *Starry Night Backyard*™ program to observe the Sun's motion on the celestial sphere. Select *Atlas* in the *Go* menu to see the entire celestial sphere, including the part below the horizon. Center on the Sun by using the *Find…* command in the *Edit* menu. Zoom out until you see about 90° of the celestial sphere. (a) Select *Auto Identify* in the *Constellations* menu to display the constellations at the center of the screen. In which constellation is the Sun located today? Is this the same as the astrological sign for today's date (see Table 1-1)? (b) Be sure you are locked on the Sun. In the Control Panel at the top of the main window, set the timestep to 3 days and click on the *Forward* button. Observe the Sun for a full year of simulated time. How many constellations does it pass through? Where does it cross the celestial equator? What path does it follow? Does it ever change direction?

71 Examine the star charts that are published monthly in such popular astronomy magazines as *Sky & Telescope* and *Astronomy.* How do they differ from the star charts within the covers of this book? On a clear, cloud-free night, use one of these star charts to locate the celestial equator and the ecliptic on the night sky. Note the inclination of the Milky Way to the ecliptic and celestial equator. What do your observations tell you about the orientation of the Earth and its orbit around the Sun relative to the rest of the Galaxy?

72 Observe the Moon on each clear night over the course of a month. Note the Moon's location among the constellations and record that location on a star chart that also shows the ecliptic. After a few weeks, your observations will begin to trace the Moon's orbit. Identify the orientation of the line of nodes by marking the points where the Moon's orbit and the ecliptic intersect. On what dates is the Sun near the nodes marked on your star chart? Compare these dates with the dates of the next solar and lunar eclipses.

73 Use *Starry Night Backyard*™ to st Moon's path in the sky and eclipses. I setting *Starry Night Backyard*™ to "A Do this by clicking on *Go* and then *Atlas.* Find on the celestial sphere by clicking on *Edit* and t... F... Type in "moon" and press enter. Increase the angle of the sky you see to 15° using the button on the upper right of the screen. Click on it and then click on 15°, which will appear in a list. Note whether the Moon lies on the ecliptic. Set the motion to increment by 6 hours per timestep. Keeping the Moon locked in the center of your screen, step ahead. (a) In what direction does the Moon move against the background of stars? Does it ever change direction? (b) Change the timestep to 1 day. Determine how many days elapse between successive times the Moon is on the ecliptic. (If you don't see the green line representing the ecliptic, select *The Ecliptic* in the *Guides* menu.) (c) Move forward in time until the Moon is either full or new *and* it is on the ecliptic. What type of eclipse could occur on that day? (d) Using Tables 1-2 and 1-3, set the program to the date of the next such eclipse. Does the Moon have the same phase as in part (c)? (e) Moving the time ahead or back by 1 hour per timestep, observe the eclipse. If the Sun and Moon "miss" each other, explain why this occurred.

74 It is quite possible that a lunar eclipse will occur while you are taking this course. If so, look up on the Internet the precise time that it will happen; in the current issue of a reference from the U.S. Naval Observatory, such as the *Astronomical Almanac* or *Astronomical Phenomena;* or in such magazines as *Sky & Telescope* and *Astronomy,* which generally run articles about eclipses the month before they happen. Make arrangements to observe the next lunar eclipse. Note the times at which the Moon enters and exits the Earth's umbra.

75 Use *Starry Night Backyard*™ to determine when the Sun rises and sets today. Similarly, find out when the Moon rises and sets today. Starting with the time set to last midnight, determine during what hours the Moon is visible during daylight hours today and during what hours it is visible at night.

# WHAT IF . . .

## EARTH'S AXIS LAY ON THE ECLIPTIC?

Imagine the Earth tilted so that its axis of rotation lies in the plane of its orbit about the Sun (see the accompanying figure). New Earth still rotates once every 24 hours. We arbitrarily fix New Earth's north pole to point toward the star Tau Tauri, a star nearly on the ecliptic, just north of the bright star Aldebaran in the constellation Taurus (see Figure 1-3).

**New Seasons** Let's see how the seasons unfold on New Earth. It is March 21, the date of the spring equinox. The Sun is directly over the equator. For the next three months, the Sun rises higher in the northern hemisphere. Unlike on our Earth, the Sun does not stop moving northward when it is over 23½° north latitude. Rather, the Sun rises farther and farther north day by day until it appears over the north pole of New Earth at the summer solstice, around June 22. Three months later, at the autumnal equinox, the Sun again rises over the equator, and day and night have the same length everywhere.

The Sun appears over the south pole of New Earth at the winter solstice, around December 22. The Sun's apparent motion through New Earth's sky completes the seasonal cycle by moving north, appearing over the equator once again around March 21.

**New Climate** Day and night take on new meanings for inhabitants of New Earth. On our Earth, the regions above the Arctic Circle and below the Antarctic Circle have days or weeks of continual light in summer and days or weeks of constant darkness in winter. But on New Earth, *every place* has extended winter periods of constant darkness followed by extended summer periods of constant daylight. Spring and fall on New Earth have daily cycles of daylight and darkness, which separate the periods of continual daylight and darkness.

**A New Day** At the latitude of Atlanta, Georgia, (33°46′) on New Earth, the day-night cycle occurs for only seven and a half months out of the year. During the other four and a half months, there is continuous day or continuous night, coupled with harsh summers and winters. With variations, this sequence of events occurs everywhere on New Earth.

The seasonal cycle on New Earth prevents the formation of permanent polar ice caps. Polar regions experience the same tropical heating and high temperatures as the equatorial regions of our Earth. The polar regions of New Earth in winter are exceptionally cold, so seasonal polar ice caps may form. Because the southern polar cap resting on Antarctica is not permanent, the oceans, and the shorelines on the continents, are higher than those on our Earth.

If seasonal polar ice caps form, the dominant force controlling weather may shift from the jet streams that circle our Earth along lines of latitude to a pole-to-pole flow. Thermal flows created by intense heating at one location and cooling at others may replace our Earth's trade winds and other east-west winds. How else would New Earth differ from our world?