Section 27.3

Objectives

- **Identify** the relative positions and motions of the Sun, Earth, and Moon.
- **Describe** the phases of the Moon.
- **Distinguish** between solstices and equinoxes.
- **Explain** eclipses of the Sun and Moon.

Review Vocabulary

revolution: the time it takes for a planetary body to make one orbit around another, larger body

New Vocabulary

ecliptic plane
solstice
equinox
synchronous rotation
solar eclipse
perigee
apogee
lunar eclipse

The Sun-Earth-Moon System

MAIN Idea Motions of the Sun-Earth-Moon system define Earth's day, month, and year.

Real-World Reading Link Have you ever tried to guess the time by judging the Sun's position? If so, you were observing an effect of the motions of the Sun-Earth-Moon system.

Daily Motions

From the vantage point of Earth, the most obvious pattern of motion in the sky is the daily rising and setting of the Sun, the Moon, stars, and everything else that is visible in the night sky. The Sun rises in the east and sets in the west, as do the Moon, planets, and stars. These daily motions result from Earth's rotation. The Sun, the Moon, planets, and stars do not orbit around Earth every day. It only appears that way because we observe the sky from a planet that rotates. But how do we know that Earth rotates?

Earth's rotation There are two relatively simple ways to demonstrate that Earth is rotating. One is to use a Foucault pendulum, like the one shown in **Figure 27.14.** A Foucault pendulum swings in a constant direction. But as Earth turns under it, the pendulum seems to shift its orientation. The second way is to observe the way that air on Earth is diverted from a north-south direction to an east-west direction by the Coriolis effect.

Day length The time period from one noon to the next is called a solar day. Our timekeeping system is based on the solar day. But the length of a day as we observe it is roughly four minutes longer than the time it takes Earth to rotate once on its axis. As Earth rotates, it also moves in its orbit and has to turn a little farther each day to align again with the Sun.

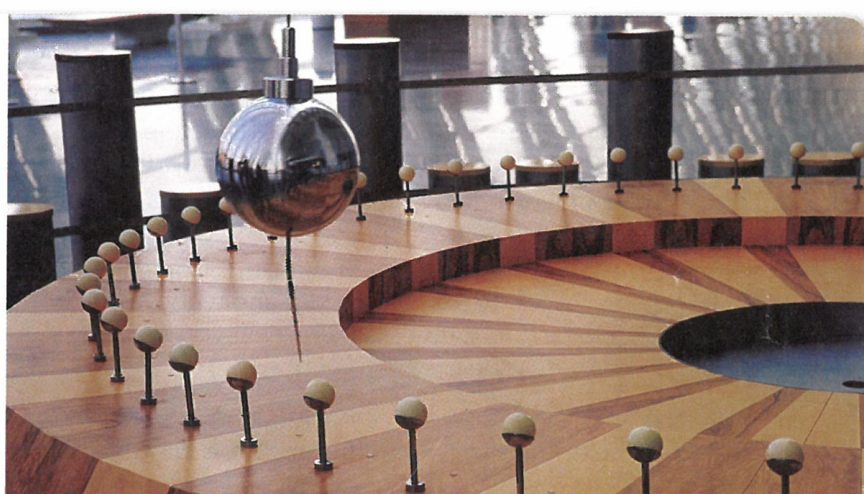
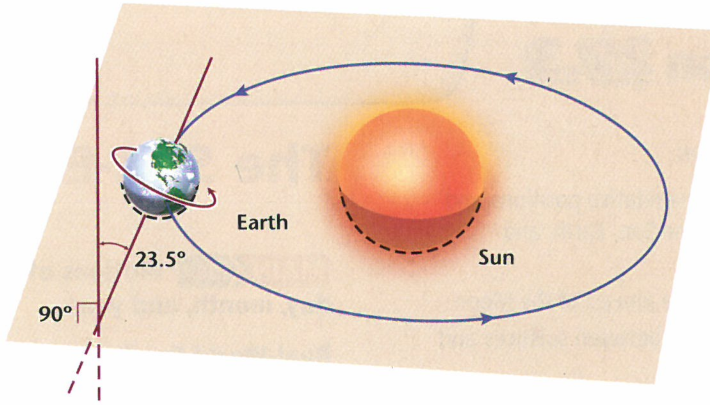


Figure 27.14 This Foucault pendulum is surrounded by pegs. As Earth rotates under it, the pendulum knocks over the pegs, showing the progress of the rotation.



■ **Figure 27.15** Earth's nearly circular orbit around the Sun lies on the ecliptic plane. When looking toward the horizon and the plane of the ecliptic, different stars are visible during the year.
Predict *Do the positions of stars vary when you look overhead?*

Annual Motions

Earth orbits the Sun in a slightly elliptical orbit, as shown in **Figure 27.15.** The plane of Earth's orbit is called the **ecliptic plane.** As Earth rotates, the Sun, planets, and constellations appear to move across the sky in a path known as the ecliptic. As Earth moves in its orbit, different constellations are visible.

Vocabulary

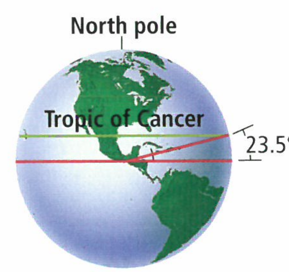
Academic vocabulary

Cycle
recurring sequence of events or phenomena
The cycle of seasons repeats every year.

The effects of Earth's tilt Earth's axis is tilted relative to the ecliptic at approximately 23.5°. As Earth orbits the Sun, the orientation of Earth's axis remains fixed in space so that, at a given time, the northern hemisphere of Earth is tilted toward the Sun, while at another point, six months later, the northern hemisphere is tipped away from the Sun. A cycle of the seasons is a result of this tilt and Earth's orbital motion around the Sun. Another effect is the changing angle of the Sun above the horizon from summer to winter. More hours of daylight cause the summer months to be warmer.

MiniLab

Predict the Sun's Summer Solstice Position



How can the Sun's position during the summer solstice be determined at specific latitudes? At summer solstice for the northern hemisphere, the Sun is directly overhead at the Tropic of Cancer.

Procedure

1. Read and complete the lab safety form.
2. Draw a straight line to represent the equator and mark the center of the line with a dot.
3. Use a **protractor** to measure the angle of latitude of the Tropic of Cancer from the equator line. Draw a line at that angle from the line's center dot.
4. Find your home latitude and measure that angle of latitude on your diagram. Draw a line from the line center for this location.
5. Measure the angle between the line for the Tropic of Cancer and the line for your location. Subtract that angle from 90°. This gives you the angle above the horizon for the maximum height of the Sun on the solstice at your location.

Analysis

1. **Describe** how the position of the Sun varies with latitude on Earth.
2. **Consider** the angle that would illustrate the winter solstice for the northern hemisphere.

Solstices Earth's orbit around the Sun and the tilt of Earth's axis are illustrated in **Figure 27.16.** Positions 1 and 3 correspond to the solstices. At a **solstice,** the Sun is overhead at its farthest distance either north or south of the equator. The lines of latitude that correspond to these positions on Earth have been identified as the Tropic of Cancer and the Tropic of Capricorn. The area between these latitudes is commonly known as the tropics. Position 1 corresponds to the summer solstice in the northern hemisphere when the Sun is directly overhead at the Tropic of Cancer, 23.5° north latitude. At this time, around June 21 each year, the number of daylight hours reaches its maximum, and the Sun is in the sky continuously within the region of the Arctic Circle. On this day, the number of daylight hours in the southern hemisphere is at its minimum, and the Sun does not appear in the region within the Antarctic Circle.

Reading Check **Identify** where the Sun is directly overhead at the summer solstice in the northern hemisphere.

As Earth moves past Position 2, the Sun's altitude decreases in the northern hemisphere until Earth reaches Position 3, known as winter solstice for the northern hemisphere. Here the Sun is directly overhead at the Tropic of Capricorn, 23.5° south latitude. This happens around December 21. On this day, the number of daylight hours in the northern hemisphere is at its minimum and the Sun does not appear in the region within the Arctic Circle. Then, as Earth continues around its orbit past Position 4, the Sun's altitude increases again until it returns to Position 1. Notice that the summer and winter solstices are reversed for those living in the southern hemisphere-June 21 is the winter solstice and December 21 is the summer solstice.

Equinoxes Positions 2 and 4, where Earth is midway between solstices, represent the equinoxes, a term meaning *equal nights*. At an **equinox,** Earth's axis is perpendicular to the Sun's rays and at noon the Sun is directly overhead at the equator. Those living in the northern hemisphere refer to Position 2 as the autumnal equinox, and Position 4 as the vernal equinox. Those in the southern hemisphere do the reverse—Positions 2 and 4 are the vernal and autumnal equinoxes, respectively.

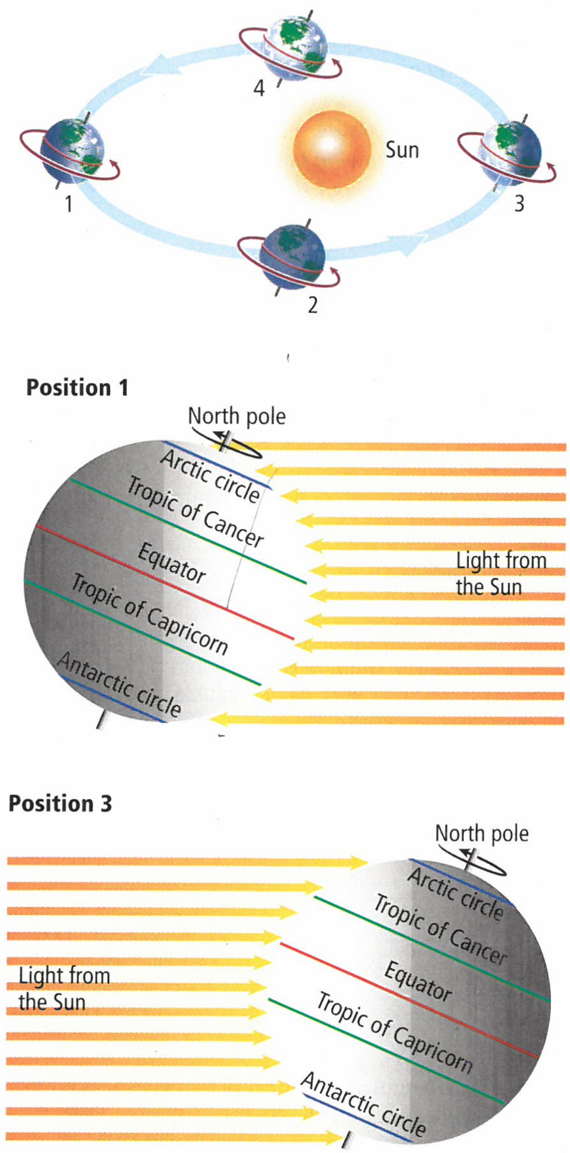
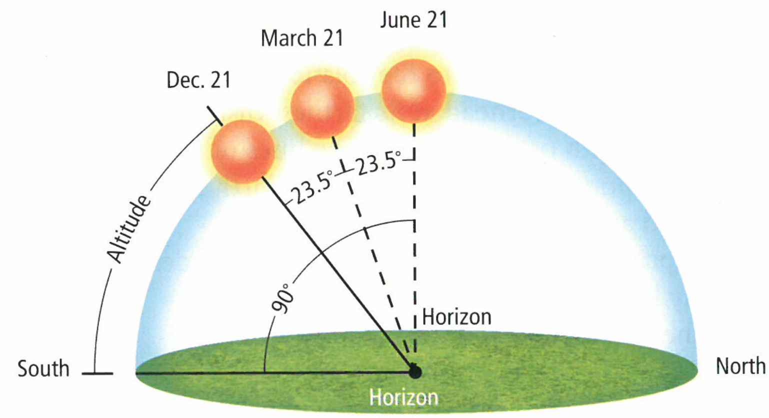


Figure 27.16 Earth's axis remains tilted at the same angle as it orbits the Sun. It points either toward or away from the Sun at solstices as in Positions 1 and 3 and to the side at equinoxes as in Positions 2 and 4.
Identify *the correct term for each position for each hemisphere.*

■ **Figure 27.17** For a person standing at 23.5° north latitude, the Sun would be directly overhead on the summer solstice. It would be at its lowest position on the horizon at the winter solstice.
Draw ***a diagram showing how the Sun's angle changes throughout the year at your latitude.***



Changes in altitude The Sun's maximum height at midday, called its zenith, varies throughout the year depending on the viewer's location. For example, on the summer solstice, a person located at 23.5° north latitude sees the Sun's zenith directly overhead. At the equinox, it appears lower, and at the winter solstice, it is at its lowest position, shown in **Figure 27.17.** Then it starts moving higher again to complete the cycle.

FOLDABLES
Incorporate information from this section into your Foldable.

Phases of the Moon

Just as the Sun appears to change its position in the sky throughout the year, the Moon also changes position relative to the ecliptic plane as it orbits Earth. The Moon's cycle is more complex, as you will learn later in this section. More striking are the changing views of the illuminated side of the Moon as it orbits Earth. The sequential changes in the appearance of the Moon are called lunar phases, and are shown in **Figure 27.18.**

VOCABULARY
SCIENCE USAGE V. COMMON USAGE
Altitude
Science usage: angular elevation of a celestial body above the horizon

Common usage: vertical elevation of a body above a surface

Reading Check **Explain** what is meant by the term *lunar phases.*

As you have read, the light given off by the Moon is a reflection of the Sun's light. In fact, one half of the Moon is illuminated at all times. How much of this lighted half is visible from Earth varies as the Moon revolves around Earth. When the Moon is between Earth and the Sun, for instance, the side that is illuminated is not visible from Earth. This phase is called a new moon.

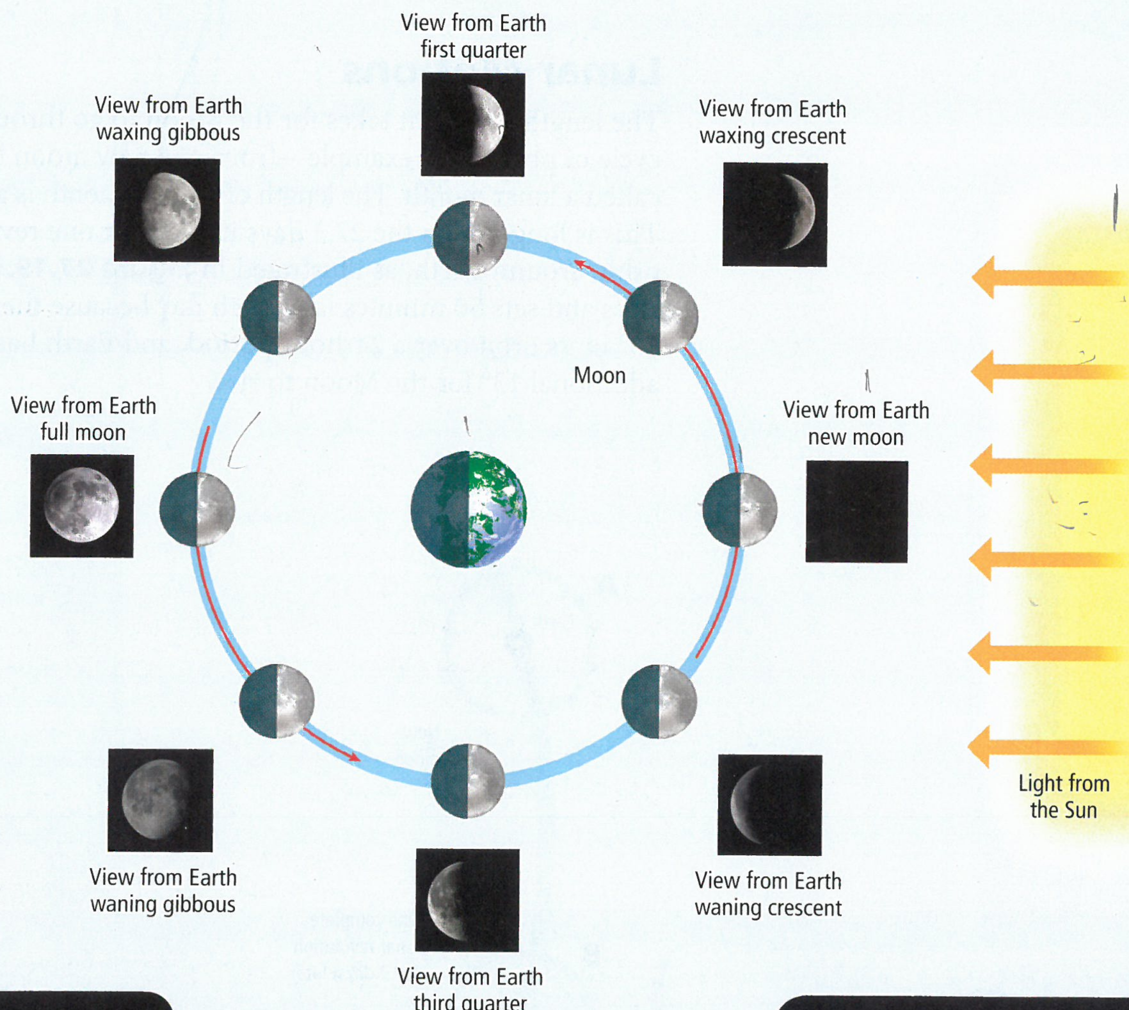
Waxing and waning Starting at the new moon, as the Moon moves in its orbit around Earth, more of the sunlit side of the Moon becomes visible. This increase in the visible sunlit surface of the Moon is called the waxing phase. The waxing phases are called waxing crescent, first quarter, and waxing gibbous. Then, as the Moon moves to the far side of the Earth from the Sun, the entire sunlit side of the Moon faces Earth. This is known as a full moon.

After the full moon, the portion of the sunlit side that is visible begins to decrease. This is called the waning phase. The waning phases are named similarly to the waxing phases, that is, waning gibbous and waning crescent. When exactly half of the sunlit portion is visible, it is called the third quarter.

Visualizing the Phases of the Moon

NATIONAL GEOGRAPHIC

Figure 27.18 One-half of the Moon is always illuminated by the Sun's light, but the entire lighted half is visible from Earth only at full moon. The rest of the time you see portions of the lighted half. These portions are called lunar phases.



Sometimes a dim image of the full moon is seen along with a crescent. This is caused by Earth's reflected light on the Moon's surface. It is often referred to as "the new moon with the old moon in its arms."

Because of the variations in the plane of the Moon's orbit, the phases might appear different—either tipped, or misshapen.

Concepts In Motion To explore more about lunar phases, visit glencoe.com.

Earth Science Online

Synchronous rotation You might have noticed that the surface features of the Moon always look the same. As the Moon orbits Earth, the same side faces Earth at all times. This is because the Moon rotates with a period equal to its orbital period, in other words, the Moon spins exactly once each time it goes around Earth. This is no coincidence. Scientists theorize that Earth's gravity slowed the Moon's original spin until the Moon reached **synchronous rotation,** the state at which its orbital and rotational periods are equal.

Lunar Motions

The length of time it takes for the Moon to go through a complete cycle of phases, for example—from one new moon to the next—is called a lunar month. The length of a lunar month is about 29.5 days. This is longer than the 27.3 days it takes for one revolution, or orbit, around Earth, as illustrated in **Figure 27.19.** The Moon also rises and sets 50 minutes later each day because the Moon moves 13° in its orbit over a 24-hour period, and Earth has to turn an additional 13° for the Moon to rise.

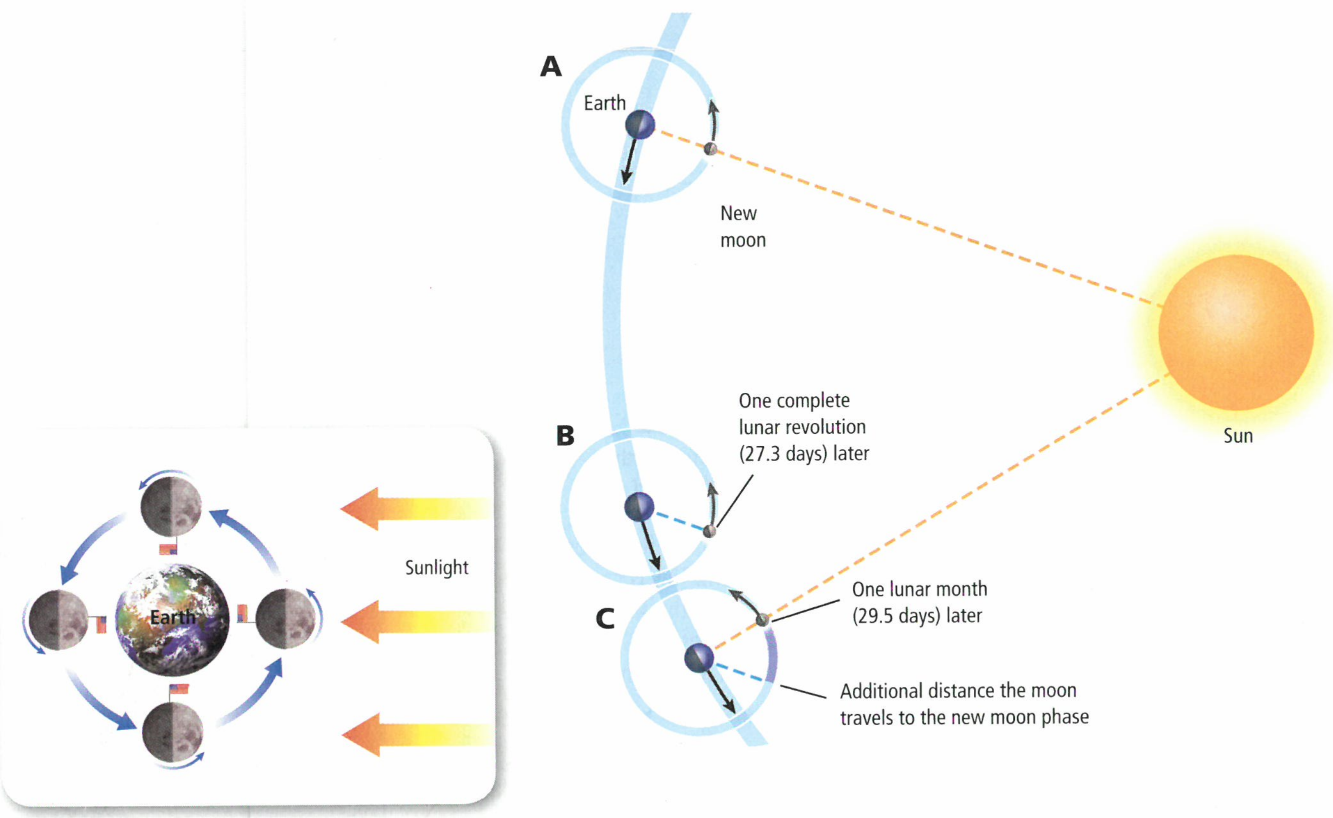
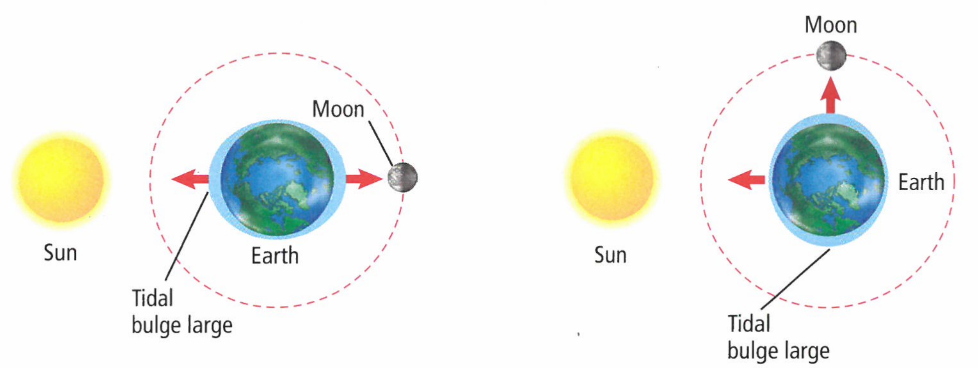


Figure 27.19 As the Moon moves from A, where it is in the new moon phase as seen from Earth, to B, it completes one revolution but is now in the waning crescent phase as seen from Earth. It must travel for 2.2 days to return to the new moon phase. The Moon rotates as it revolves, keeping the same side facing Earth, as shown in the inset.



■ **Figure 27.20** Alignment of the Sun and the Moon produces the spring tides shown on the left. Neap tides, shown on the right, occur when the Sun and the Moon are at right angles.

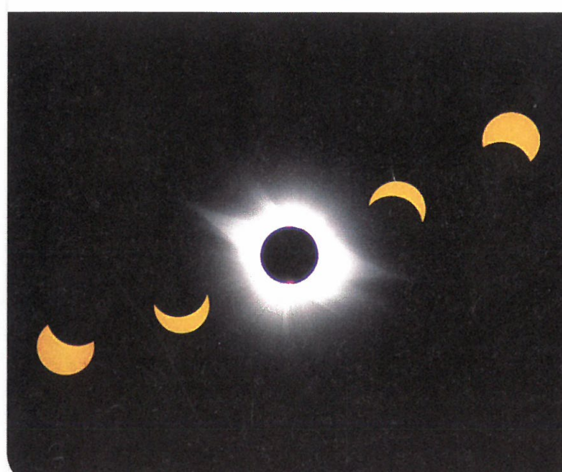
Tides One effect the Moon has on Earth is causing ocean tides. The Moon's gravity pulls on Earth along an imaginary line connecting Earth and the Moon, and this creates bulges of ocean water on both the near and far sides of Earth. Earth's rotation also contributes to the formation of tides, as you learned in Chapter 15. As Earth rotates, these bulges remain aligned with the Moon, so that a person at a shoreline on Earth's surface would observe that the ocean level rises and falls every 12 hours.

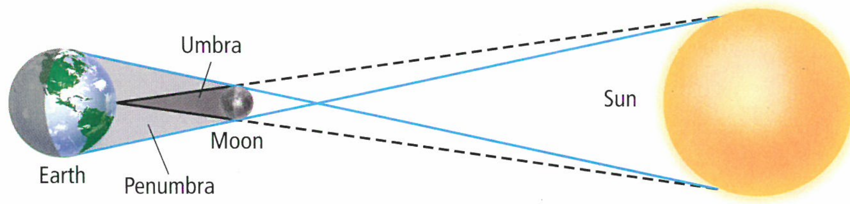
Spring and neap tides The Sun's gravitational pull also affects tides, but the Sun's influence is half that of the Moon's because the Sun is farther away. However, when the Sun and the Moon are aligned along the same direction, their effects are combined, and tides are higher than normal. These tides, called spring tides, are especially high when the Moon is nearest Earth and Earth is nearest the Sun in their slightly elliptical orbits. When the Moon is at a right angle to the Sun-Earth line, the result is lower-than-normal tides, called neap tides. The Sun and the Moon alignments during spring and neap tides are shown in **Figure 27.20.**

Solar Eclipses

A **solar eclipse** occurs when the Moon passes directly between the Sun and Earth and blocks the Sun from view. Although the Sun is much larger than the Moon, it is far enough away that they appear to be the same size when viewed from Earth. When the Moon perfectly blocks the Sun's disk, only the dim, outer gaseous layers of the Sun are visible. This spectacular sight, shown in **Figure 27.21,** is called a total solar eclipse. A partial solar eclipse is seen when the Moon blocks only a portion of the Sun's disk.

■ **Figure 27.21** The stages of a total solar eclipse are seen in this multiple-exposure photograph.
Explain ***why the Moon seems to cross the Sun at an angle rather than directly right to left.***





■ **Figure 27.22** During a solar eclipse, the Moon passes between Earth and the Sun. Those on Earth within the darkest part of the Moon's shadow (umbra) see a total eclipse. Those within the lighter part, or penumbral shadow, see only a partial eclipse.

Concepts In Motion

Interactive Figure To see an animation of an eclipse, visit glencoe.com.

How solar eclipses occur Each object in the solar system creates a shadow as it blocks the path of the Sun's light. This shadow is totally dark directly behind the object and has a cone shape. During a solar eclipse, the Moon casts a shadow on Earth as it passes between the Sun and Earth. This shadow consists of two regions, as illustrated in **Figure 27.22.** The inner, cone-shaped portion, which blocks the direct sunlight, is called the umbra. People who witness an eclipse from within the umbra shadow see a total solar eclipse. That means they see the Moon completely cover the face of the Sun. The outer portion of this shadow, where some of the Sun's light still reaches, is called the penumbra. People in the region of the penumbra shadow see a partial solar eclipse, where a part of the Sun's disk is blocked by the Moon. Typically, the umbral shadow is never wider than 270 km, so a total solar eclipse is visible from a very small portion of Earth, whereas a partial solar eclipse is visible from a much larger portion.

PROBLEM-SOLVING LAB

Interpret Scientific Illustrations

How can you predict how a solar eclipse will look to an observer at various positions?

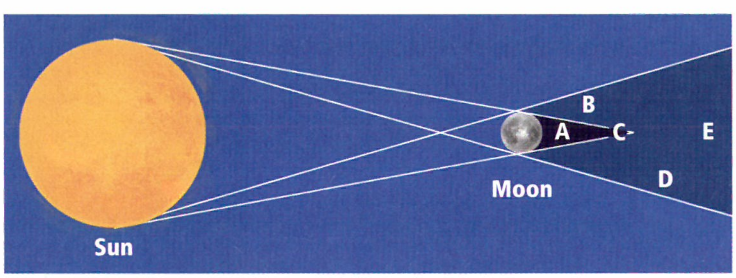
The diagram below shows the Moon eclipsing the Sun. The Sun will appear differently to observers located at Points A through E.

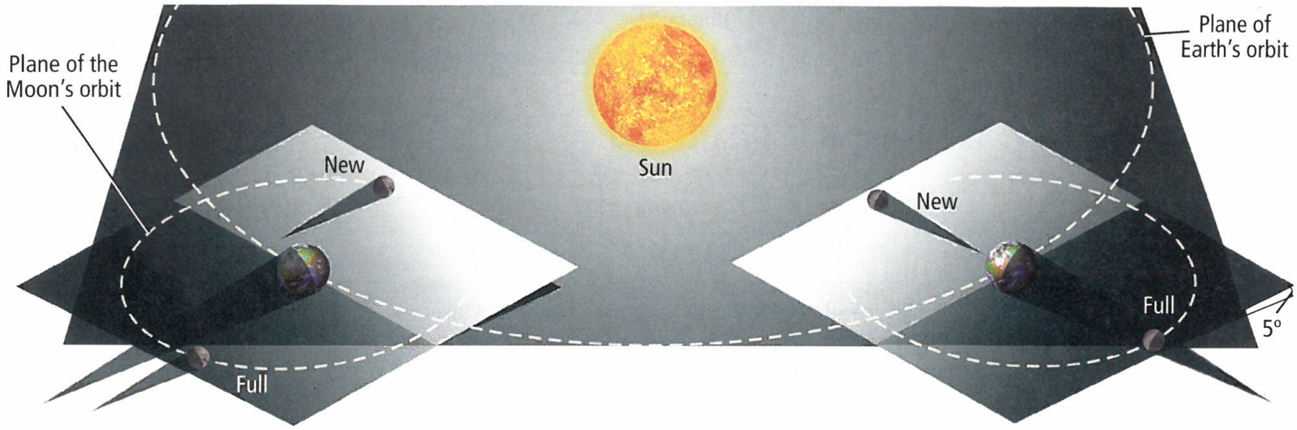
Analysis

1. **Observe** the points in relation to the position of the Moon's umbra and penumbra.

Think Critically

2. **Draw** how the solar eclipse would appear to an observer at each labeled point.
3. **Design** a data table to display your drawings.
4. **Classify** the type of solar eclipse represented in each of your drawings.





■ **Figure 27.23** Eclipses can take place only when Earth, the Moon, and the Sun are perfectly aligned. This can happen only when the Moon's orbital plane and ecliptic plane intersect along the Sun-Earth line, as shown in diagram on the right. In the left diagram, this does not happen, and the Moon's shadow misses Earth.

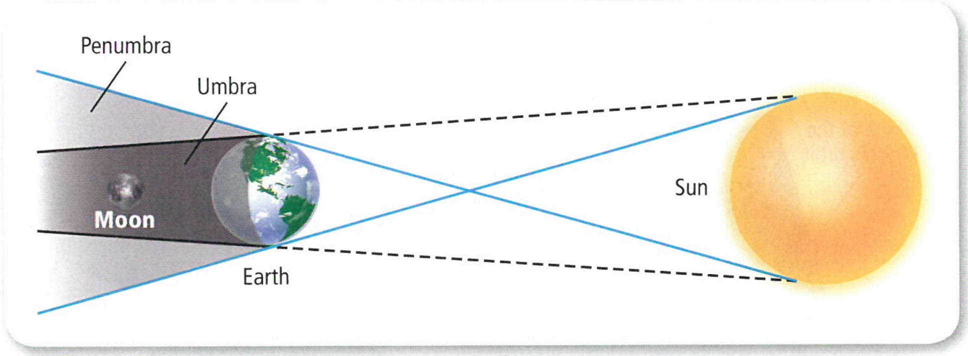
Effects of tilted orbits You might wonder why a solar eclipse does not occur every month when the Moon passes between the Sun and Earth during the new moon phase. This does not happen because the Moon's orbit is tilted 5° relative to the ecliptic plane. Normally, the Moon passes above or below the Sun as seen from Earth, so no solar eclipse takes place. Only when the Moon crosses the ecliptic plane is it possible for the proper alignment for a solar eclipse to occur, but even that does not guarantee a solar eclipse. The plane of the Moon's orbit also rotates slowly around Earth, and a solar eclipse occurs only when the intersection of the Moon and the ecliptic plane is in a line with the Sun and Earth, as **Figure 27.23** illustrates.

Reading Check **Determine** why a total solar eclipse does not occur every month.

Annular eclipses Not only does the Moon move above and below the plane of Earth and the Sun, but the Moon's distance from Earth increases and decreases as the Moon moves in its elliptical orbit around Earth. The closest point in the Moon's orbit to Earth is called **perigee,** and the farthest point is called **apogee.** When the Moon is near apogee, it appears smaller from Earth, and thus will not completely block the disk of the Sun during an eclipse. This is called an annular eclipse because, as **Figure 27.24** shows, a ring of the Sun, called the annulus, appears around the dark Moon. Earth's orbit also has a perigee and apogee. When Earth is nearest the Sun and the Moon is at apogee from Earth, the Moon would not block the Sun entirely. The opposite is true for Earth at apogee to the Sun and the Moon at perigee to Earth.

■ **Figure 27.24** An annular eclipse takes place when the Moon is too far away for its umbral shadow to reach Earth. A ring, or annulus, is left uncovered.

Predict *Would annular eclipses occur if the Moon's orbit were a perfect circle?*



■ **Figure 27.25** When the Moon is completely within Earth's umbra, a total lunar eclipse takes place, as shown in the diagram. The darkened Moon often has a reddish color, as shown in the photo, because Earth's atmosphere bends and scatters the Sun's light.

Lunar Eclipses

A **lunar eclipse** occurs when the Moon passes through Earth's shadow. As illustrated in **Figure 27.25,** this can happen only at the time of a full moon when the Moon is on the opposite side of Earth from the Sun. The shadow of Earth has umbral and penumbral portions, just as the Moon's shadow does. A total lunar eclipse occurs when the entire Moon is within Earth's umbra. This lasts for approximately two hours. During a total lunar eclipse, the Moon is faintly visible, as shown in **Figure 27.25,** because sunlight that has passed near Earth has been filtered and refracted by Earth's atmosphere. This light can give the eclipsed Moon a reddish color as Earth's atmosphere bends the red light into the umbra, much like a lens. Like solar eclipses, lunar eclipses do not occur every full moon because the Moon in its orbit usually passes above or below the Sun as seen from Earth.

Section 27.3 Assessment

Section Summary

- Earth's rotation defines one day, and Earth's revolution around the Sun defines one year.
- Seasons are caused by the tilt of Earth's spin axis relative to the ecliptic plane.
- The gravitational attraction of both the Sun and the Moon causes tides.
- The Moon's phases result from our view of its lighted side as it orbits Earth.
- Solar and lunar eclipses occur when the Sun's light is blocked.

Understand Main Ideas

1. MAIN Idea **State** one proof that Earth rotates, one proof Earth rotates in 24 hours, and make one observation that proves it revolves around the Sun in one year.
2. **Compare** solar and lunar eclipses, including the positions of the Sun, Earth, and Moon.
3. **Diagram** the waxing and waning phases of the Moon.
4. **Analyze** why the Moon has a greater effect on Earth's tides than the Sun, even though the Sun is more massive.

Think Critically

5. **Relate** what you have learned about lunar phases to how Earth would appear to an observer on the Moon. Diagram the positions of the Sun, Earth, and the Moon and draw how Earth would appear in several positions to explain your answer.

MATH in Earth Science

6. Consider what would happen if Earth's axis were tilted 45°. At what latitudes would the Sun be directly overhead on the solstices and the equinoxes?

Earth Science Online Self-Check Quiz glencoe.com