

Unit 8

Beyond Earth

The nighttime sky appears to contain only stars, which belong to the Milky Way (right). However, a variety of objects, such as planets, stars, nebulae, and galaxies can be found. Despite their distance, each of these objects impacts our existence here on Earth. Galaxies provide a place for stars to develop. Nebulae provide the materials to form stars. Stars, like the Sun, provide energy and create elements. Star formation often results in the formation of planets.

Unit Contents

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Go to the [National Geographic Expedition](#) on page 902 to learn more about topics that are connected to this unit.



Milky Way Galaxy

Chapter 28

The Sun- Earth-Moon System

What You'll Learn

- How light and telescopes are used to explore the sky.
- How to identify features on the Moon.
- What theories are used to describe the Moon's origin.
- How to analyze the motions of the Sun, Earth, and the Moon.

Why It's Important

The motions of the Sun-Earth-Moon system affect Earth physically, as well as play an important role in our timekeeping system.



To find out more about the Sun-Earth-Moon system, visit the Earth Science Web Site at earthgeu.com


Discovery Lab

The Sun is about 109 times larger in diameter than Earth, and Earth is about 3.7 times larger in diameter than the Moon. The Moon is 30 times farther from Earth than Earth's diameter, and the Sun is 400 times farther away from Earth than is the Moon. In this activity, you will compare relative sizes and distances within the Sun-Earth-Moon system.

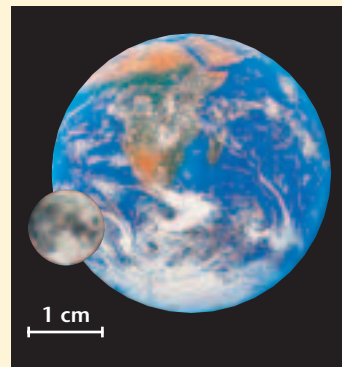
1. Calculate the diameters of Earth and the Sun using a scale in which the Moon's diameter is equal to 1 cm.
2. Using your calculations in step 1, calculate the distance between Earth and the Moon and the distance between Earth and the Sun.

Make a Scale Model

3. Cut out circles to represent your scaled Earth and Moon, and place them at the scaled distance apart.

 **CAUTION:**
Always handle sharp objects with care.

Observe In your science journal, describe the sizes of your cut-out Earth and Moon compared to the distance between them. Infer why you were not instructed to cut out a scaled Sun and place it at the scaled distance. How would you change this model so that it would fit in your classroom?



SECTION

28.1

Tools of Astronomy

OBJECTIVES

- **Describe** *electromagnetic radiation.*
- **Explain** *how telescopes work.*
- **Describe** *space exploration.*

VOCABULARY

refracting telescope
reflecting telescope
interferometry
spinoff

The best tool, and in most cases the only tool, that astronomers can use to learn about the universe is the light that comes to Earth from distant objects. Apart from a few solar-system objects that have been sampled by direct probes and particles and fragments that have made their way into Earth's atmosphere or to Earth's surface, there is no other way to study the cosmos except to analyze the radiation emitted from it. Therefore, it is necessary to understand this radiation.

RADIATION

The radiation from the cosmos that scientists study is electromagnetic radiation. Electromagnetic radiation consists of electric and magnetic disturbances, traveling through space as waves. The human eye can sense only a limited range of all the various wavelengths of electromagnetic radiation. This range is called visible light. Electromagnetic radiation includes not just visible light, but also infrared and ultraviolet radiation, radio waves, microwaves, X rays, and gamma rays.

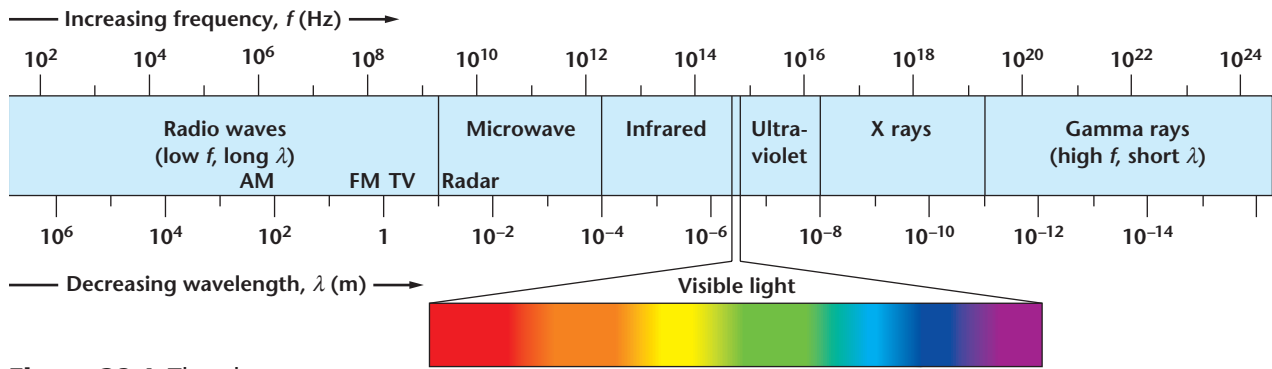


Figure 28-1 The electromagnetic spectrum ranges from radio waves to gamma rays. Wavelength and frequency are related by $c = \lambda f$. Notice how small the range of visible light is compared to the rest of the spectrum.

You may be familiar with some forms of electromagnetic radiation. For example, ultraviolet radiation causes sunburn, and X rays help doctors observe internal injuries and diagnose bone diseases. All the types of electromagnetic radiation, arranged according to wavelength and frequency, form the electromagnetic spectrum, illustrated in *Figure 28-1*.

Electromagnetic radiation is classified by its wavelengths. Wavelength is the distance between peaks on a wave. You can see in *Figure 28-1* that red light has longer wavelengths than blue light, and radio waves have much longer wavelengths than gamma rays. Electromagnetic radiation also can be classified according to frequency, which is the number of waves or oscillations occurring per second. The visible light portion of the spectrum has frequencies ranging from 4.3×10^{14} to 7.5×10^{14} Hz. Frequency is related to wavelength by the mathematical relationship $c = \lambda f$, where c is the speed of light (3.0×10^8 m/s), λ is the wavelength, and f is the frequency. Note that all types of electromagnetic radiation travel at the same speed, c .

TELESCOPES

Objects in space emit radiation in all portions of the electromagnetic spectrum. The ability to modify telescopes with different detectors and mirror shapes to observe all wavelengths, especially those the human eye cannot detect, is just one of the benefits of using a telescope. Another benefit is that a telescope collects electromagnetic radiation from a distant object and focuses it at a point where the image of the object can be studied or recorded. The human eye does the same thing with visible light, but the eye is much more limited. A typical human-eye pupil has a diameter of up to 7 mm when it is adapted to darkness, whereas a telescope might be as large as 10 m in diameter. The area of the opening through which electromagnetic

Using Math

Using Numbers For a telescope with a circular collector, the collecting area is πr^2 , where r is the telescope's radius. If one telescope is twice as large as another, it will collect four times as much light. How much more visible light will a visible-light telescope with a radius of 5 m collect than a human eye that has a pupil with a 1 mm radius?

radiation enters determines the collecting power of a telescope. The larger the opening, the more electromagnetic radiation that can be gathered. A telescope's ability to collect a large amount of electromagnetic radiation allows astronomers to observe faint or weakly emitting objects.

A third benefit of telescopes is that they allow astronomers to use specialized equipment. A photometer, for example, is used to measure the intensity of visible light. A fourth benefit is that telescopes can be used to make time exposures with the aid of cameras or other imaging devices. In time exposures, electromagnetic radiation is collected over a long period of time. With visible light, the human eye "photographs" what it sees about 10 times per second, so an object too dim to be perceived in one-tenth of a second cannot be seen. This is why telescopes are able to detect objects that are too faint for the human eye to see.

Refracting and Reflecting Telescopes Two different types of telescopes are used to focus visible light. The first telescopes, invented around the year 1600, used lenses to bring visible light to a focus and are called **refracting telescopes**, or refractors. The largest lens on such a telescope is called the objective lens. *Figure 28-2A* illustrates how a simple refracting telescope works. In 1668, a new telescope was designed that used mirrors. Telescopes that bring visible light to a focus with mirrors are called **reflecting telescopes**, or reflectors. *Figure 28-2B* illustrates how a simple reflecting telescope works.

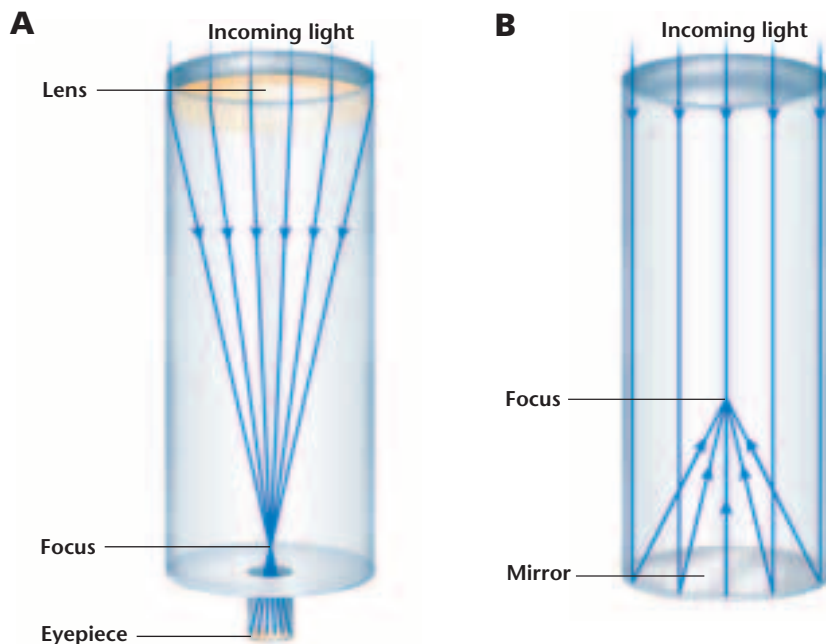


Figure 28-2 A refracting telescope (**A**) uses a lens to bring light to a focus. The largest lens is called the objective lens. A reflecting telescope (**B**) uses a mirror to bring light to a focus. The largest mirror is called the primary mirror.

Although both refracting and reflecting telescopes are still in use today, the majority are reflectors. Most telescopes used for scientific study are located at observatories far from city lights, usually at high elevations where there is less atmosphere overhead to blur images. Some of the best observatory sites in the world are located high atop mountains in the southwestern United States, along the peaks of the Andes Mountains in Chile, and on the summit of Mauna Kea, the gigantic volcano on the island of Hawaii.

Telescopes at Other Wavelengths In addition to using visible-light telescopes, astronomers observe the universe at wavelengths that the human eye cannot detect. For all telescopes, the goal is to bring as much electromagnetic radiation as possible to a focus. Infrared and ultraviolet radiation can be focused by mirrors in much the same way as visible light. X rays cannot be focused by normal mirrors, and thus, special designs must be used. Because gamma rays cannot be focused, telescopes designed to detect the extremely short wavelengths of this type of radiation can determine little more than the general direction from which the rays come.

Figure 28-3 shows a radio telescope consisting of a large dish, or antenna, which resembles a satellite TV dish. The dish plays the same role as the primary mirror in a reflecting telescope, by reflecting radio waves to a focus above the dish. There, a receiver converts the radio waves into electrical signals that can be stored in a computer for analysis. A process called interferometry, which has been used

with radio telescopes for a number of years, is now being applied to other telescopes as well. **Interferometry** is the process of linking separate telescopes together so that they act as one telescope. The detail in the images that they produce improves as the distance between the telescopes increases. One of the best-known examples of this technology is the Very Large Array near Socorro, New Mexico.

Figure 28-3 The Owens Valley Radio Telescope in California is a typical radio telescope.



NATIONAL GEOGRAPHIC

To learn more about the *Hubble Space Telescope*, go to the [National Geographic Expedition](#) on page 902.

SATELLITES, PROBES, AND SPACE-BASED ASTRONOMY

Astronomers often have to send their instruments into space to collect the information they seek. One reason for this is that Earth's atmosphere blocks infrared radiation, ultraviolet radiation, X rays, and gamma rays. In addition, when Earth's atmosphere does allow certain wavelengths to pass through, the images are blurred. Another reason for sending instruments into space is to make close-up observations and even obtain samples from nearby objects in the solar system. Since the late 1960s, American, European, Soviet (later, Russian), and Japanese space programs have launched many space-based observatories to collect data in different wavelengths.

One of the best-known space-based observatories, shown in **Figure 28-4**, is the *Hubble Space Telescope (HST)*, which was launched in 1990 and is scheduled to operate until 2010. *HST* was designed to obtain sharp visible-light images without atmospheric interference, and also to make observations in infrared and ultraviolet wavelengths. Other space-based telescopes, such as the *Far Ultraviolet Spectroscopic Explorer*, the *Chandra X-Ray Observatory*, and the *Spitzer Space Telescope*, are used to observe other wavelengths that are blocked by Earth's atmosphere.

Spacecraft In addition to making observations from above Earth's atmosphere, space-based exploration can be achieved by sending spacecraft directly to the bodies being observed. Robotic probes make close-up observations and sometimes land to collect information directly. Probes are practical only for objects within our solar system, because the stars are much too far away. The robot *Sojourner*, part of the *Pathfinder* probe, explored Mars for almost 3 months in 1997. More recently, the twin robots *Spirit* and *Opportunity* conducted scientific experiments on Mars in 2004 (**Figure 28-5**).

Figure 28-5 One of the twin robots, *Spirit* and *Opportunity*, is shown on a simulated Martian surface on Earth during one of its tests.



Figure 28-4 On April 25, 1990, the *Hubble Space Telescope* was released from the shuttle *Discovery* during mission STS-31.





Figure 28-6 This photo shows the partially completed *International Space Station* as it orbits Earth.

Human Spaceflight Exploring objects in space has been a top priority for scientists, but they have also been very interested in exploring the effects of space, such as weightlessness. The most recent human explorations and studies have been accomplished with the space shuttle program, which began in 1981. The space shuttle provides an environment for scientists to study the effects of weightlessness on humans, plants, the growth of crystals, and other phenomena. However, because shuttle missions last a maximum of just 17 days, long-term effects must be studied in space stations.

A multi-country space station called the *International Space Station*, shown in **Figure 28-6**, is the ideal environment to study the long-term effects of space. Human habitation and research aboard the *International Space Station* began in 2000.

Spinoffs Space-exploration programs have benefited our society far beyond our increased understanding of space. Many technologies that were originally developed for use in space programs are now used by people all over the world. Did you know that the technology for the space shuttle's fuel pumps led to the development of pumps used in artificial hearts? Or that the Apollo program led to the development of cordless tools? In fact, more than 1400 different NASA technologies have been passed on to commercial industries for common use, and are called **spinoffs**. Each year, new technologies are developed that not only benefit astronomers and space exploration, but society also.

SECTION ASSESSMENT

1. How do the various types of electromagnetic radiation differ from each other?
2. What are the advantages of using a telescope compared to making observations with the unaided eye?
3. What is interferometry, and how does it affect the images that are produced?
4. Why do astronomers send telescopes and probes into space?
5. How are space stations beneficial?
6. **Thinking Critically** How would humans' lives and our perceptions of the universe be different without space-based technology and exploration?

SKILL REVIEW

7. **Comparing and Contrasting** Compare and contrast refracting telescopes and reflecting telescopes. For more help, refer to the *Skill Handbook*.



The Moon is a familiar object in the night sky. Despite its proximity to Earth, however, the origins and nature of the Moon have been elusive. Only with advances in telescope and spacecraft technology over the past 100 years have people begun to understand the Moon.

REACHING FOR THE MOON

Astronomers have learned much about the Moon from telescopic observations. However, most of our knowledge of the Moon comes from explorations by space probes, such as *Lunar Prospector* and *Clementine*, and astronauts. Plans for a crewed lunar expedition began in the late 1950s. The first step was taken in 1957 with the launch of the first satellite, *Sputnik I*, by the Soviet Union. Shortly thereafter, in 1961, Soviet cosmonaut Yuri A. Gagarin became the first human in space.

The United States' Project Mercury launched the first American, Alan B. Shepard Jr., shown in **Figure 28-7**, into space on May 5, 1961. Project Gemini launched two-person crews into space, and on July 20, 1969, the Apollo program landed Neil Armstrong and Buzz Aldrin on the Moon, during *Apollo 11*.

Lunar Properties Earth's moon is unique among all the moons in the solar system. It is one of the largest moons, especially compared to the size of the planet it orbits. The Moon's radius is about 27 percent of Earth's radius, and its mass is more than 1 percent of Earth's mass, as shown in **Table 28-1**. Most moons are much smaller than this in relation to the size of the planets they orbit.

The orbit of the Moon is also unusual in that the Moon is relatively farther from Earth than most moons are from the planets they orbit. Earth's moon is a solid, rocky body, in contrast to the icy composition of the moons of the outer planets Jupiter, Saturn, Uranus, Neptune, and Pluto. Also, Earth's moon is the only large moon among the inner planets. Mercury and Venus have no moons at all, and the moons of Mars are just two tiny chunks of rock.

Table 28-1 The Moon and Earth

	The Moon	Earth
Mass (kg)	7.349×10^{22}	5.9736×10^{24}
Radius (km)	1737.4	6378.1
Volume (km ³)	2.1968×10^{10}	1.08321×10^{12}
Density (kg/m ³)	3340	5515

OBJECTIVES

- **Describe** the development of exploration of the Moon.
- **Identify** features on the Moon.
- **Explain** the theories about how the Moon formed.

VOCABULARY

albedo
highland
mare
impact crater
ejecta
ray
rille
regolith

Figure 28-7 American astronaut Alan B. Shepard Jr., in the *Mercury 7* capsule, prepares for launch.



The Lunar Surface Although the Moon is the brightest object in our nighttime sky, the lunar surface is actually quite dark. The **albedo** of the Moon, the amount of sunlight that its surface reflects, is very small—only about 0.07 (7 percent). In contrast, Earth has an average albedo of nearly 0.31 (31 percent). The sunlight that is absorbed by the surface of the Moon is responsible for the extreme differences in temperatures on its surface. Because the Moon has no atmosphere, sunlight can heat the Moon’s surface to temperatures as high as 400 K (127°C). During the absence of sunlight, the Moon’s surface temperature can drop to a chilly 100 K (−173°C).

The physical surface of the Moon is very different from that of Earth. There is no erosion on the Moon—except for surface creep and wear caused by recent impacts—because it has no atmosphere or flowing water. The surface of the Moon consists of several features. Regions called **highlands**, shown in *Figure 28-8A*, are light in color, mountainous, and heavily covered with craters. Regions called **maria** (*singular, mare*), shown in *Figure 28-8A*, are dark, smooth plains, which on average are 3 km lower in elevation than the highlands.

All of the craters on the Moon are **impact craters**, formed when objects from space crashed into the lunar surface. The material blasted out during these impacts fell back to the surface as **ejecta**. Some craters have long trails of ejecta, called **rays**, that radiate outward. Rays are visible as light-colored streaks, as shown in *Figure 28-8B*.

In contrast to the crater-covered highlands, the surfaces within maria are quite smooth. However, the maria do have a few scattered craters and **rilles**, which are meandering, valleylike structures, as illustrated in *Figure 28-8D*. In addition, around some of the maria are mountain ranges, shown in *Figure 28-8C*.

Why does the Moon have many craters, while Earth has few? Early in the formation of the solar system, Earth was bombarded just as heavily as the Moon, but erosion on Earth has eliminated traces of all but the youngest craters. On the Moon, craters are preserved until one impact covers another.

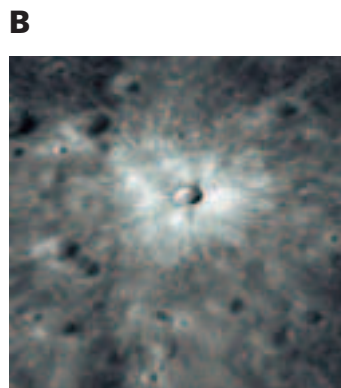
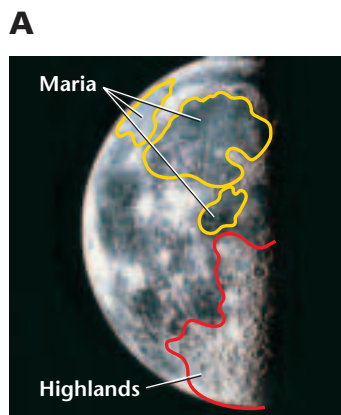


Figure 28-8 Maria are dark, plains areas on the Moon, while the highlands are very mountainous and heavily cratered (**A**). A relatively recent crater on the Moon has very light ejecta (**B**). This is a mountain range on the surface of the Moon (**C**). Humboldt Crater has a network of rilles surrounding it (**D**).

Composition The Moon is made up of minerals similar to those of Earth—mostly silicates. The highlands, which cover most of the lunar surface, are predominately lunar breccias, which are rocks formed by the fusing together of smaller pieces of rock during impacts. Unlike sedimentary breccias on Earth, most of the lunar breccias are composed of plagioclase feldspar, a silicate containing high quantities of calcium and aluminum but low quantities of iron. The maria are predominately basalts that differ from those on Earth in that they contain no water.

HISTORY OF THE MOON

The entire lunar surface is very old. Radiometric dating of lunar rocks from the highlands indicates an age between 3.8 and 4.6 billion years. Based on the ages of the highlands and the frequency of the impact craters that cover them, scientists theorize that the Moon was heavily bombarded during its first 800 million years, which resulted in the breaking and heating of rocks on the surface of the Moon. This formed a layer of loose, ground-up rock, called **regolith**, on the surface of the Moon. The regolith averages several meters in thickness, but it varies considerably depending on location.

The maria, only slightly younger than the highlands, are between 3.1 and 3.8 billion years old. After the period of intense bombardment in which the highlands formed, lava welled up from the Moon's interior and filled in the large impact basins to form the maria. The maria have remained relatively free of craters because fewer impacts have occurred on the Moon since the time when they formed. However, flowing lava in the maria scarred their surfaces with rilles, which are much like lava tubes found on Earth. During the formation of the maria, the lava often did not fill the basins completely. Instead, the rims of the basins remained above the lava and formed the mountain ranges that now exist around many of the maria. As shown in **Figure 28-9**, there are virtually no maria on the far side of the Moon, which is covered almost completely with highlands. Scientists hypothesize that this is because the crust is twice as thick on the far side, which would have made it increasingly difficult for lava to reach the lunar surface. You will determine the relative ages of the Moon's surface features in the *Mapping GeoLab* at the end of this chapter.

Figure 28-9 This photo of the far side of the Moon, shows the heavily cratered surface of the highlands.



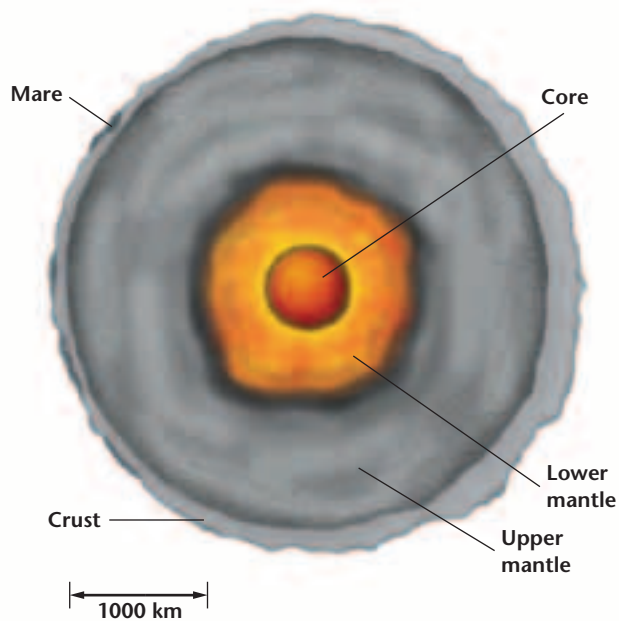


Figure 28-10 The Moon has a layered structure similar to Earth's.

Tectonics on the Moon? Mountain ranges around maria were formed by impacts, not tectonically, as mountain ranges on Earth are. But is that enough evidence to conclude that the Moon is not tectonically active? Scientists infer from seismometer data that the Moon, like Earth, has a layered structure, which consists of the crust, the upper mantle, the lower mantle, and the core, as illustrated in *Figure 28-10*. The crust varies in thickness and is thickest on the far side. The Moon's upper mantle is solid, its lower mantle is partially molten, and its core is made of solid iron. Seismometers also measure moonquake strength and their frequency. Although the Moon experiences a moonquake that would be strong enough to cause dishes to fall out of a cupboard approximately once a year,

scientists theorize that the Moon is not tectonically active. The fact that the Moon has no active volcanoes and no significant magnetic field supports scientists' theory that tectonics are not occurring on the Moon.

Formation Theories Several theories have been proposed to explain the Moon's unique properties. One of these is the capture theory, which proposes that as the solar system was forming, a large object ventured too near to the forming Earth, became trapped in its gravitational pull, and formed into what is now the Moon. One problem with this theory is that something would have had to slow down the passing object for it to become trapped instead of continuing on its original path. Another problem with the capture theory is that Earth and the Moon are composed of very similar elements. If the Moon had been captured, we would expect the crusts of the Moon and Earth to have different compositions, rather than similar ones.

Another theory, called the simultaneous formation theory, accounts for the problems with the capture theory. According to this theory, the Moon and Earth formed at the same time and in the same general area, and thus the materials from which they formed were essentially the same. Also, because they formed in the same general area, the Moon did not have to be slowed down to become gravitationally trapped. This theory does not account for the different amounts of iron on Earth and on the Moon, however. The Moon is iron poor, while on Earth, iron is relatively abundant.

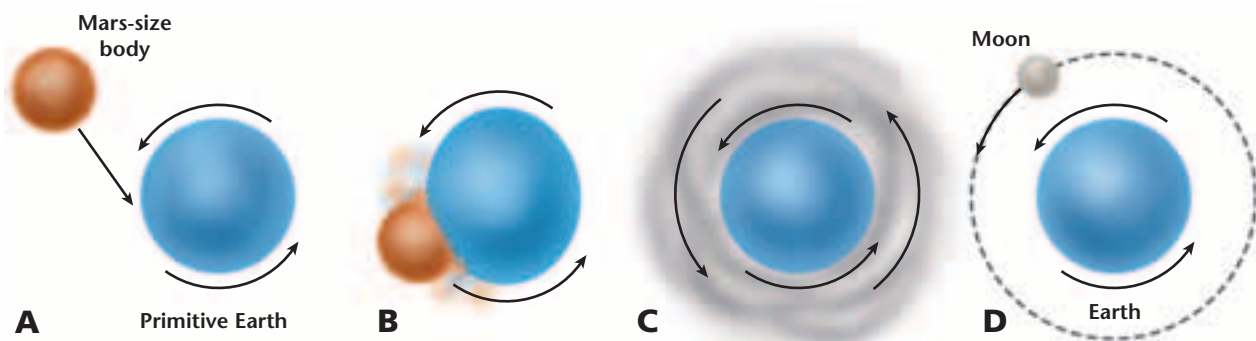


Figure 28-11 The impact theory suggests that a Mars-sized body (**A**) collided with Earth. The impact (**B**) threw material from the body and Earth into space (**C**). This material eventually merged together to form the Moon (**D**). (Not to scale)

The most commonly accepted theory of how the Moon formed, the impact theory, can explain astronomers' observations as a whole. Computer models indicate that the Moon formed as the result of a gigantic collision between Earth and a Mars-sized object about 4.5 billion years ago, when the solar system was forming. As a result of the collision, materials from the incoming body and from Earth's outer layers were ejected into space, where they then merged together to form the Moon, as illustrated by *Figure 28-11*. This model accounts for why the Moon is so similar to Earth in chemical composition. If this model is correct, then the Moon is made up of material that was originally part of Earth's iron-deficient crust as well as material that was once part of Earth's mantle. Heat produced by the impact would have evaporated any water that was present and resulted in lunar minerals lacking water. Despite scientists' uncertainty about how the Moon formed, we do know that it plays a vital role in the Sun-Earth-Moon system, as you will learn in the following section.

SECTION ASSESSMENT

1. How is Earth's moon different from the moons of other planets?
2. Why are there many visible craters on the Moon, but few on Earth?
3. Why do scientists believe that tectonic activity is not occurring on the Moon?
4. What is the most accepted theory of how the Moon formed, and what are the problems with the other theories?
5. **Thinking Critically** How would the surface of the Moon look different if the crust on the far side were the same thickness as the crust on the near side?

SKILL REVIEW

6. **Concept Mapping** Use the following terms to construct a concept map to organize the major ideas in this section. For more help, refer to the *Skill Handbook*.

1. highlands

2. lava fills in some craters

3. the Moon forms

4. maria

5. mountain ranges

6. heavy cratering

OBJECTIVES

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

VOCABULARY

ecliptic
 summer solstice
 winter solstice
 autumnal equinox
 vernal equinox
 synchronous rotation
 solar eclipse
 perigee
 apogee
 lunar eclipse

The relationships between the Sun, Moon, and Earth are important to us in many ways. The Sun provides light and warmth, and it is the source of most of the energy that fuels our society. Additionally, the Moon raises tides in our oceans and illuminates our sky with its monthly cycle of phases. Every society from ancient times to the present has based its calendar and its timekeeping system on the apparent motions of the Sun and Moon.

DAILY MOTIONS

The most obvious pattern of motion in the sky is the daily rising and setting of the Sun, the Moon, the stars, and everything else that is visible in the sky. The Sun rises in the east and sets in the west, as do the Moon, planets, and stars. Today, we understand that these daily motions result from Earth's rotation. The Sun, Moon, planets, and stars do not orbit around Earth every day. It only appears that way to us because we observe the sky from a planet that rotates once every day, or 15° per hour. But how do we know that Earth is rotating?

Earth's Rotation There are two relatively simple ways to demonstrate that Earth is rotating. One is to use a pendulum, which is a weight on a string or wire that is suspended from a support and can swing freely. A Foucault pendulum, which has a long wire and a heavy weight, will swing in a constant direction. But as Earth turns, it appears from our point of view that the pendulum gradually shifts its orientation. With a Foucault pendulum, pegs are often placed on the floor in a circle so that as Earth turns, the pendulum, shown in **Figure 28-12**, eventually knocks over each of the pegs. The second method of demonstrating that Earth rotates makes use of the fact that flowing air and water on Earth are diverted from a north-south direction to an east-west direction as a result of Earth's rotation. This diversion of direction is called the Coriolis effect, which you learned about in Chapter 12.

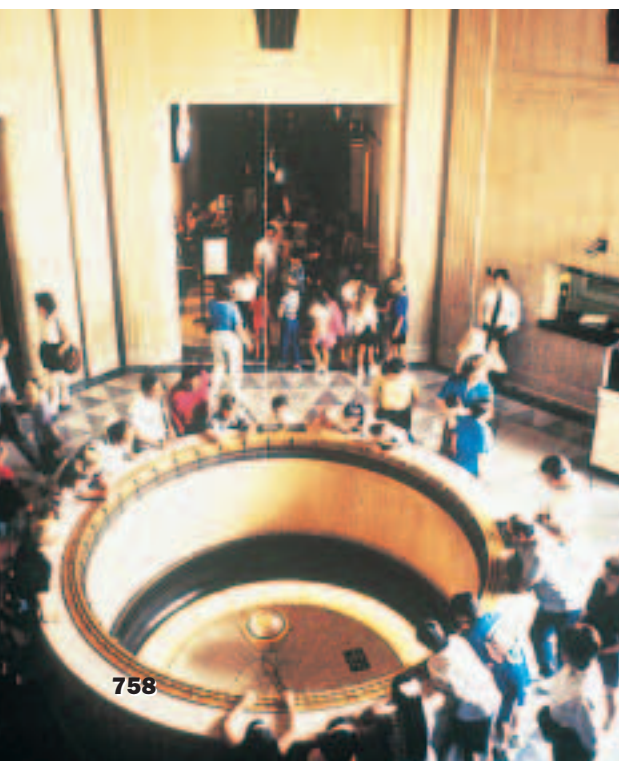


Figure 28-12 A Foucault pendulum, such as this one at the Griffith Observatory in Los Angeles, California, demonstrates that Earth is rotating.

The length of a day as we observe it is a little longer than the time it takes Earth to rotate once on its axis. This is because as Earth rotates, it also moves along in its orbit and has to turn a little farther. The time period from one sunrise or sunset to the next is called a solar day. Our timekeeping system is based on the solar day.

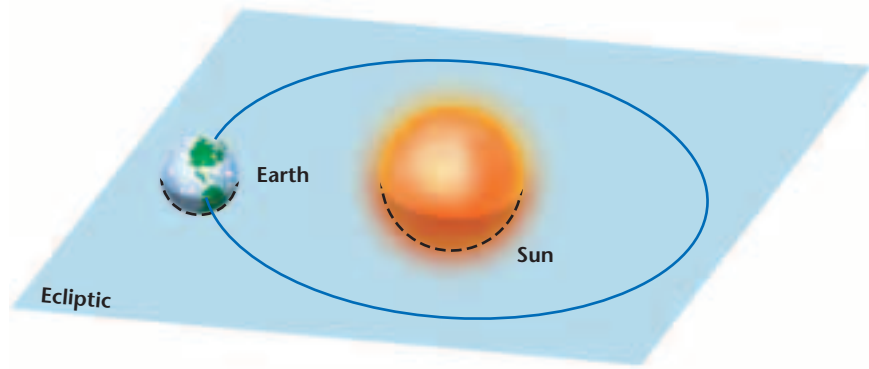


Figure 28-13 The ecliptic is the plane that contains Earth's orbit around the Sun. (Not to scale)

ANNUAL MOTIONS

As you know, the weather changes throughout the year. The length of days varies, and temperatures may range from cold to hot, depending on the latitude where you live. These annual changes are the result of Earth's orbital motion about the Sun. The plane in which Earth orbits about the Sun is called the **ecliptic**, as illustrated in *Figure 28-13*.

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 one point, 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. Our seasons, as discussed in Chapter 14, are created by this tilt and by Earth's orbital motion around the Sun.

As a result of the tilt of Earth's axis and Earth's motion around the Sun, the Sun changes its altitude in the sky. The way in which altitude of the Sun is measured is illustrated in *Figure 28-14*.

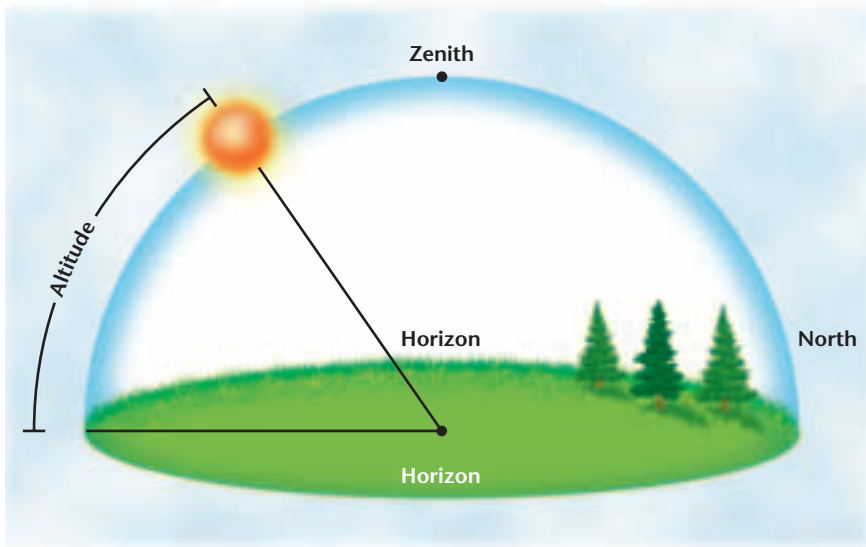
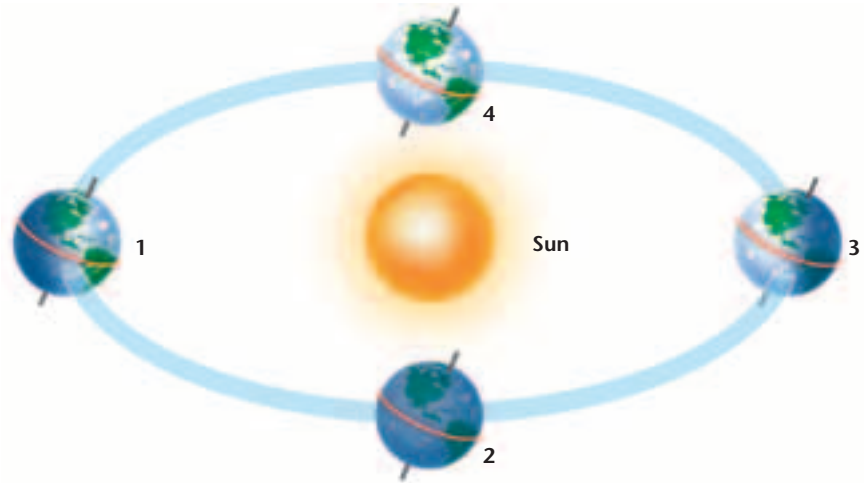


Figure 28-14 Altitude is measured in degrees from the observer's horizon to the object. There are 90 degrees from the horizon to the point directly overhead, called the zenith of the observer.

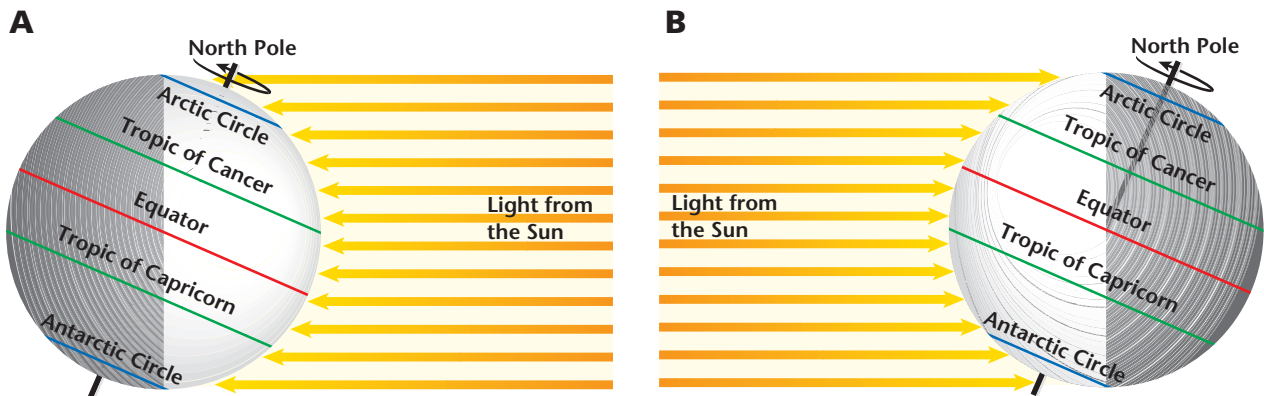
Figure 28-15 As Earth orbits the Sun, Earth's tilted axis points in the same direction. (Not to scale)



You've probably noticed the change in altitude of the Sun during the northern hemisphere's summer, when the Sun appears higher in the sky than it does during the northern hemisphere's winter. This change occurs gradually throughout Earth's orbit in a cyclic pattern.

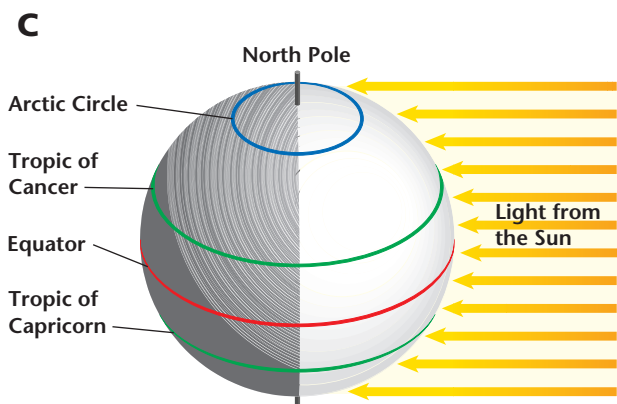
Solstices Earth's varying position in its orbit around the Sun and the tilt of Earth's axis are illustrated in *Figure 28-15*. As Earth moves from position 1, through position 2, to position 3, the altitude of the Sun decreases in the northern hemisphere. Once Earth is at position 3, the Sun's altitude starts to increase as Earth moves through position 4 and back to position 1. Position 1 corresponds to the Sun's maximum altitude in the sky in the northern hemisphere. At this position, called the **summer solstice**, the Sun is directly overhead at the Tropic of Cancer, which is at 23.5° north latitude, as illustrated in *Figure 28-16A*. On the summer solstice, which occurs around June 21 each year, the number of daylight hours for the northern hemisphere is at its maximum, while it is at its minimum for the southern hemisphere. During the summer solstice, the Sun does not set in the region within the arctic circle, and it does not rise in the region within the antarctic circle.

Figure 28-16 The Sun's rays are vertical at the Tropic of Cancer during the summer solstice (A), at the Tropic of Capricorn during the winter solstice (B), and at the equator during the autumnal equinox (C) and the vernal equinox (D).



Conversely, when Earth is in position 3 and the northern hemisphere is tilted away from the Sun, the Sun has reached its lowest altitude in the sky. At this position, called the **winter solstice**, the Sun is directly overhead at the Tropic of Capricorn at 23.5° south latitude, as illustrated in *Figure 28-16B*. On the winter solstice, which occurs around December 21 each year, the number of daylight hours in the northern hemisphere is at its minimum, while it is at its maximum for the southern hemisphere. During the winter solstice, the Sun never rises in the region within the arctic circle, and it never sets in the region within the antarctic circle. You will model the Sun's position as seen from your location during the summer solstice in the *MiniLab* on this page.

Equinoxes At positions 2 and 4 in *Figure 28-15*, Earth's axis is not pointed at the Sun. As a result, both hemispheres receive equal amounts of sunlight, and the Sun is directly overhead at the equator. Thus, the lengths of day and night are equal for both the northern and southern hemispheres when Earth is at position 2, called the **autumnal equinox**, illustrated in *Figure 28-16C*, and position 4, called the **vernal equinox**, illustrated in *Figure 28-16D*. The term *equinox* means "equal nights."



MiniLab

The Sun's Position

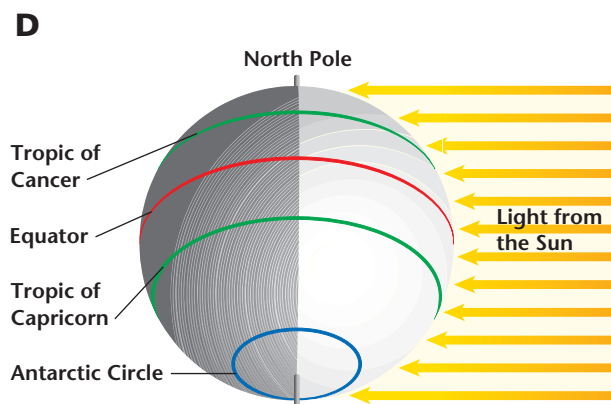
Model the overhead position of the Sun at various latitudes during the summer solstice.

Procedure

1. Draw a circle to represent Earth. Also draw the equator.
2. Use a protractor to find the location of the Tropic of Cancer. Draw a line from Earth's center to the Tropic of Cancer.
3. Using a map, locate that latitude at which you live. With the protractor, mark that latitude on your diagram. Draw a line from Earth's center to this location.
4. Measure the angle between the line to the Tropic of Cancer and the line to your location.
5. Choose two different latitudes, then repeat steps 3 and 4 for these latitudes.

Analyze and Conclude

1. How does the angle vary with latitude?
2. At what southern latitude would you not see the Sun above the horizon?
3. How would the angle change if you used the Tropic of Capricorn?



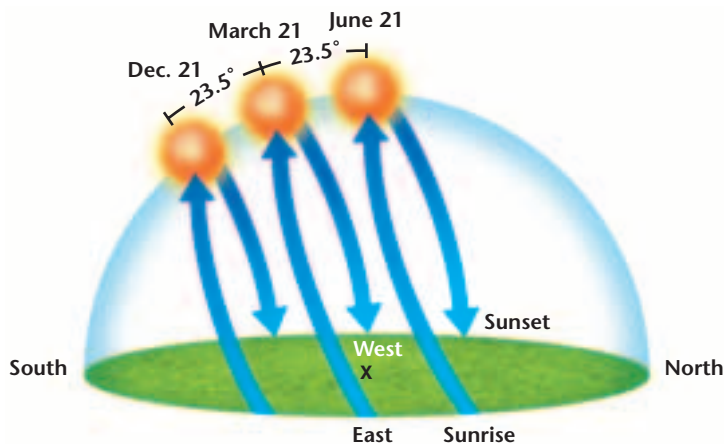


Figure 28-17 For a person standing at the x at 23.5° north latitude, the Sun would appear in these positions on the winter solstice, the vernal equinox, and the summer solstice. On the autumnal equinox, the Sun would be at the same altitude as on the vernal equinox.

Figure 28-18 These photos show the phases of the Moon, except the new moon phase, in which no portion of the Moon's illuminated surface is visible from Earth. The photo starts on the left with a waxing crescent, and ends on the right with a waning crescent. **What are the phases in between called?**



At the Tropic of Cancer or Tropic of Capricorn, the Sun is 23.5° from the point directly overhead during the equinoxes. In the *Science & Math* feature at the end of this chapter, you will learn how Eratosthenes used the Sun's position and shadows to calculate the circumference and radius of Earth.

Figure 28-17 illustrates how the Sun would appear in the sky to a person at 23.5° north latitude during the solstices and the equinoxes. As you can see, the position of the Sun affects how directly sunlight strikes Earth. When the Sun is at a lower altitude, the sunlight that strikes Earth is spread out over a larger area.

PHASES OF THE MOON

Just as the Sun appears to change its position in the sky, so, too, does the Moon. This is a result of the movement of the Moon around Earth and of our changing viewpoint on Earth relative to the Sun. The sequential changes in the appearance of the Moon are called lunar phases, shown in **Figure 28-18**.

You have learned that the Moon does not emit visible light. Instead, we see the Moon's reflection of the Sun's light. When the Moon is between Earth and the Sun, however, we cannot see the Moon because the sunlit side is facing away from us. This dark Moon positioned between Earth and the Sun is called a new moon.

As the Moon moves along in its orbit, as illustrated in **Figure 28-19**, the amount of reflected sunlight that we can see increases. The increase in the portion of the sunlit side of the Moon that we see is called waxing. When we can see less than half of the sunlit portion of the Moon during this increase, it is called a waxing crescent. When we can see more than half of the sunlit portion of the Moon during this increase, it is called a waxing gibbous. Between these phases, the

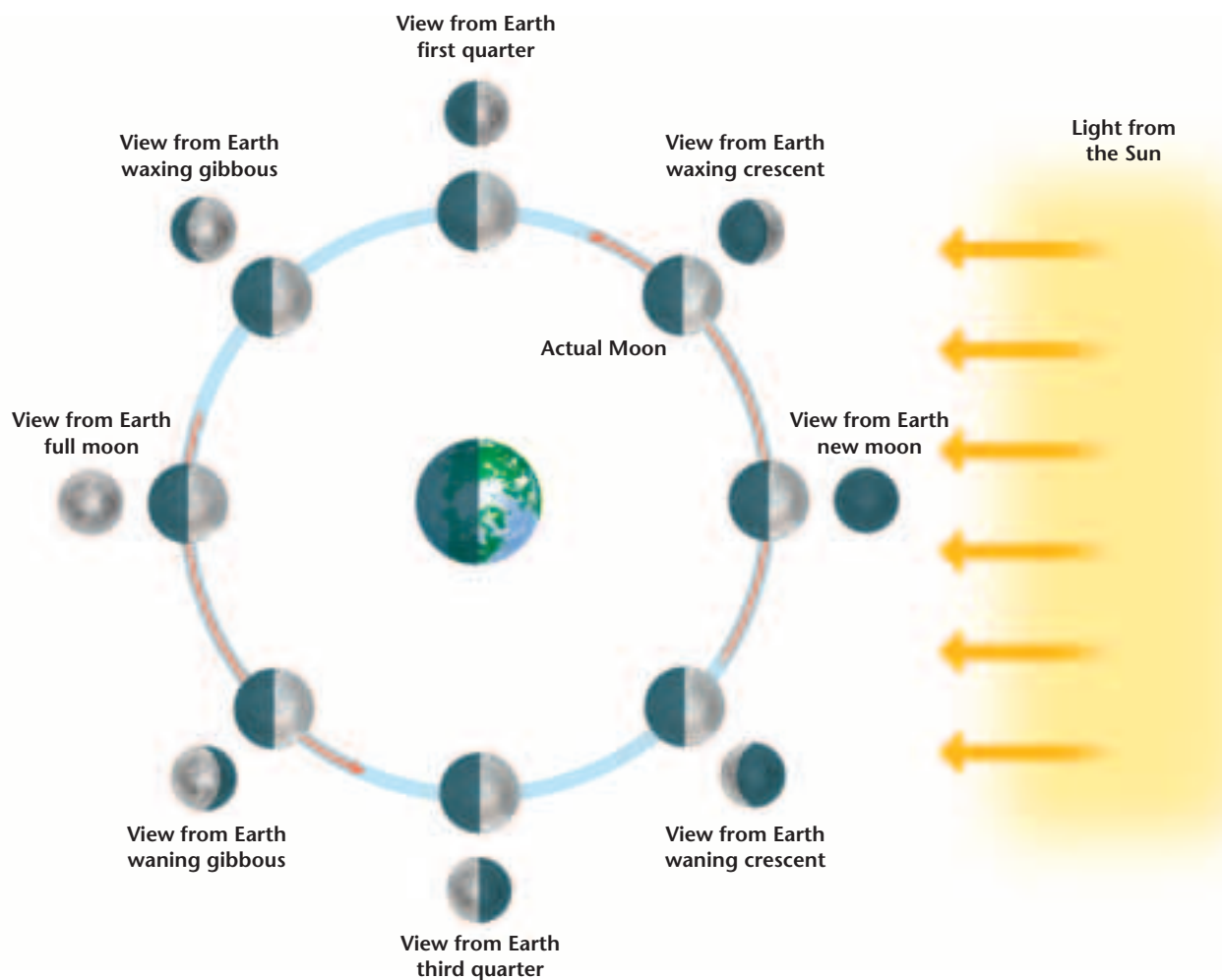


Figure 28-19 As the Moon orbits Earth, the portion of the illuminated side of the Moon that we see from Earth changes, thus creating phases. (Not to scale)

Moon reaches a point in its orbit when we see half of the sunlit side. This is called the first quarter. As the Moon continues farther in its orbit, it moves to a position where it is once again aligned with the Sun. This time, Earth is between the Moon and Sun, and we are able to see the entire sunlit side of the Moon. This is known as a full moon.

Once a full moon is reached, the portion of the sunlit side that we see begins to decrease as the Moon moves back toward the new-moon position. The decrease in the amount of the sunlit side of the Moon that we see is called waning. As in the waxing phases, there is a period during the waning phases when we can see more than half of the sunlit portion of the Moon, as well as a period when we can see less than half of the sunlit portion. These phases are called waning gibbous and waning crescent, respectively. In the middle of the waning phases, the Moon is in a position in its orbit where we can see half of the sunlit portion. This is called the third quarter.

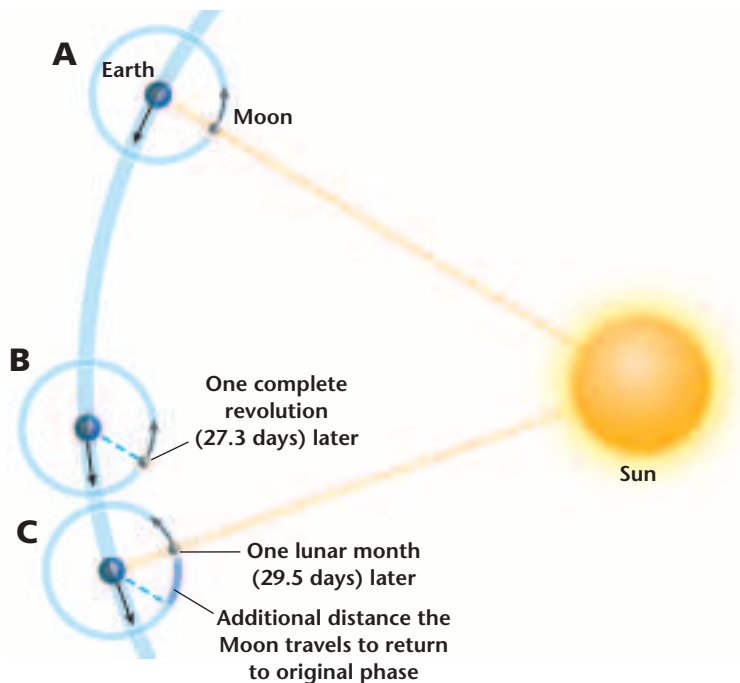


Figure 28-20 As the Moon moves from position **A**, where the Moon is in new moon phase as seen from Earth, to position **B**, it completes one revolution and is in the waning crescent phase as seen from Earth. At position **C**, the Moon has traveled for another 2.2 days and is back to the new moon phase, completing a lunar month. (Not to scale)

MOTIONS OF THE MOON

The length of time it takes for the Moon to go through a complete cycle of phases, for example, from one full moon to the next, is called a lunar month. The length of a lunar month is about 29.5 days, which is longer than the 27.3 days it takes for one revolution, or orbit, around Earth, as illustrated in *Figure 28-20*. The Moon also rises and sets 50 minutes later each day because the Moon has moved 13° in its orbit over a 24-hour period, and Earth has to turn an additional 13° for the Moon to rise.

Tides One of the Moon's effects on Earth is the formation of 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.

The Sun's gravitational effect on the formation of tides is about half that of the Moon's, because the Sun is farther away. However, when the Sun and Moon are aligned along the same direction, the effects of the Sun and Moon combine, 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 noncircular orbits. When the Moon is at a right angle to the Sun-Earth line, the result is lower-than-normal tides, called neap tides.

Synchronous Rotation You might have noticed that the illuminated surface of the Moon always looks the same. As the Moon orbits Earth, the same side faces Earth at all times. This is because the Moon is rotating with a period equal to its orbital period, so it spins exactly once each time it goes around Earth. This is not a 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.



Figure 28-21 This multiple-exposure photograph, taken July 11, 1991, in California, shows a total solar eclipse in the middle of the sequence.

SOLAR ECLIPSES

A **solar eclipse** occurs when the Moon passes directly between the Sun and Earth and blocks our view of the Sun. Although the Sun is much larger than the Moon, it is much farther away, which causes the Sun and Moon to appear to be the same size when viewed from Earth. When the Moon perfectly blocks the Sun's disk, we see only the dim, outer gaseous layers of the Sun. This spectacular sight, shown in **Figure 28-21**, is called a total solar eclipse. A partial solar eclipse is seen when the Moon blocks only a portion of the Sun's disk.

The difference between a partial and a total solar eclipse can be explained by the fact that the Moon casts a shadow on Earth. This shadow consists of two regions, as illustrated in **Figure 28-22**. The inner portion, which does not receive direct sunlight, is called the umbra. People who witness an eclipse from the umbra see a total solar eclipse. People in the outer portion of this shadow, where some of the Sun's light reaches, are in the penumbra. They see a partial solar eclipse where part of the Sun's disk is still visible. 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.

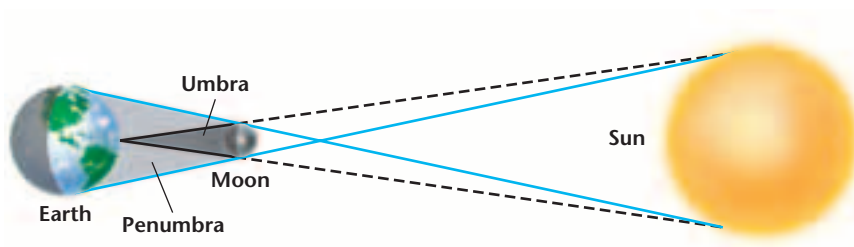


Figure 28-22 During a solar eclipse, the Moon passes between the Sun and Earth. People within the umbral shadow witness a total solar eclipse, while people within the penumbral shadow witness a partial solar eclipse. (Not to scale)

Earth Science Online

Topic: Next Solar Eclipse
To find out more about solar eclipses, visit the Earth Science Web Site at earthgeu.com

Activity: Research future solar eclipses. When will the next solar eclipse be visible in your area?



Figure 28-23 This annular eclipse, partly obscured by clouds, was photographed in San Diego, California, in January, 1992.

The Effects of Orbits You might wonder why a solar eclipse does not occur every month, as 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. Usually, the Moon passes north or south of the Sun as seen from Earth, so no solar eclipse takes place. Only when the Moon crosses the ecliptic is it possible for the proper alignment for a solar eclipse to occur, but even that is not enough to 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 is in a line with the Sun and Earth. Hence, the proper alignment for solar eclipses does not occur every month with each new moon.

Not only does the Moon move above and below the plane of Earth and the Sun, but also, 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 as seen from Earth, and thus it does not completely block the disk of the Sun during an eclipse. This is called an annular eclipse because from Earth, a ring of the Sun called an annulus is visible around the dark Moon, as shown in **Figure 28-23**. You'll experiment with the different types of solar eclipses in the *Problem-Solving Lab* on this page.

Problem-Solving Lab

Interpreting Scientific Illustrations

Predict how a solar eclipse will look Depending on an observer's location, a solar eclipse can look different.

Analysis

1. Make a drawing of how the solar eclipse would appear to an observer at each labeled location in the illustration.

Thinking Critically

2. Design a data table showing your drawings of how the eclipse would appear at each location.
3. What type of eclipse does each of your drawings represent? Include this information in your data table.



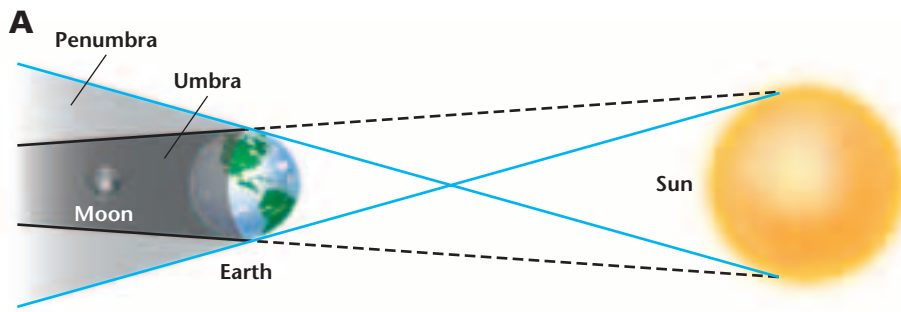


Figure 28-24 When the Moon is completely within the umbra of Earth's shadow (**A**), we observe a total lunar eclipse (**B**). (Illustration not to scale)



LUNAR ECLIPSES

A **lunar eclipse** occurs when the Moon passes through Earth's shadow. As illustrated in **Figure 28-24A**, this can happen only at the time of a full moon, when the Moon is in the opposite direction 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, and totality lasts for approximately two hours. During a total lunar eclipse, the Moon is faintly visible, as shown in **Figure 28-24B**, because sunlight that has passed near Earth has been 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.

Solar and lunar eclipses occur in almost equal numbers, with slightly more lunar eclipses. The maximum number of eclipses, solar and lunar combined, that can be seen in a year is seven. The last time this occurred was in 1982, and it won't happen again until 2038.

SECTION ASSESSMENT

1. What are the causes of Earth's seasons?
2. What would our seasons be like if Earth's axis were not tilted?
3. Explain why the Moon goes through phases as seen from Earth.
4. Describe solar and lunar eclipses.
5. **Thinking Critically** If Earth's axis were tilted 45° , at what latitudes would the Sun be directly overhead on the solstices and the equinoxes?

SKILL REVIEW

6. **Formulating Models** If you were to observe Earth from the Moon, you would see that it goes through phases. Draw a diagram illustrating these phases and the positions of the Sun, Earth, and the Moon. For more help, refer to the *Skill Handbook*.



Relative Ages of Lunar Features

It is possible to use the principle of cross-cutting relationships, discussed in Chapter 21, to determine the relative ages of surface features on the Moon. By observing which features cross-cut others, you can infer which is older.

Preparation

Problem

How can you use images of the Moon to interpret relative ages of lunar features?

Materials

metric ruler
pencil

Procedure

1. Observe photos I and II. Use the letters to identify the oldest feature in each photo using the principle of cross-cutting relationships. List the other features in order of their relative ages.
2. Observe photo III. List the mare, rille, and craters in order of their relative ages.
3. Observe photo IV. Use the principle of cross-cutting relationships, along with your knowledge of lunar history, to identify the features and list them in order of their relative ages.

Analyze

1. What problems did you encounter?
2. Based on information from all the photos, what features are usually the oldest? The youngest?
3. Could scientists use the process you did to determine the exact age difference between two overlapping craters? Why or why not?
4. If the small crater in photo II, labeled A, is 44 km across, what is the scale for that photo? What is the size of the large crater, labeled D?

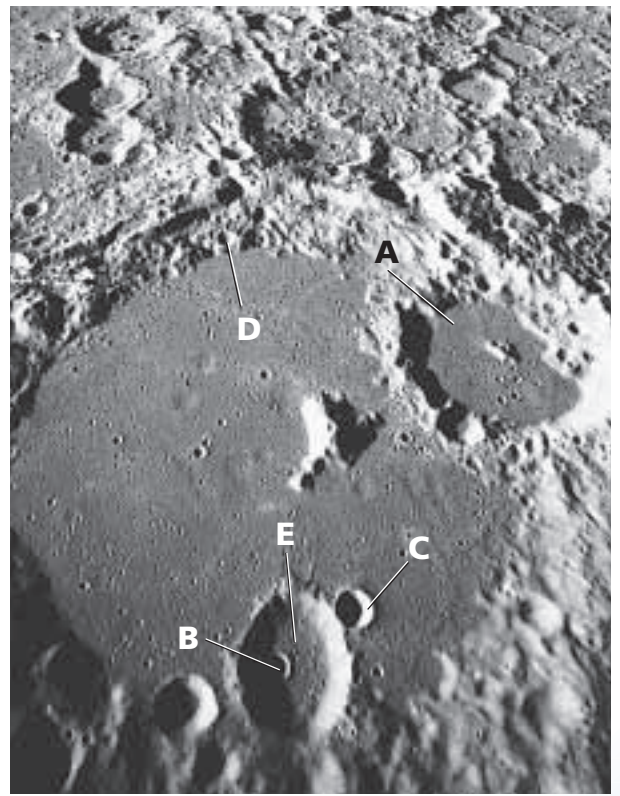
Conclude & Apply

1. Which would be older, a crater that had rays crossing it, or the crater that caused the rays? Explain.
2. Is there some type of relative-age dating that scientists can use to analyze craters on Earth? Explain.
3. What do you think caused the chain of craters in photo I? If the crater labeled A is approximately 17 km across, how long is the chain of craters?

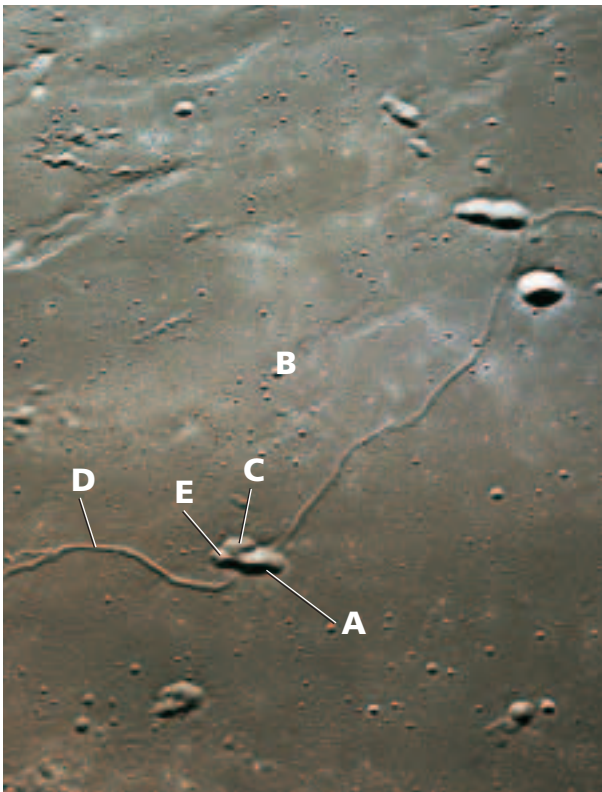
I



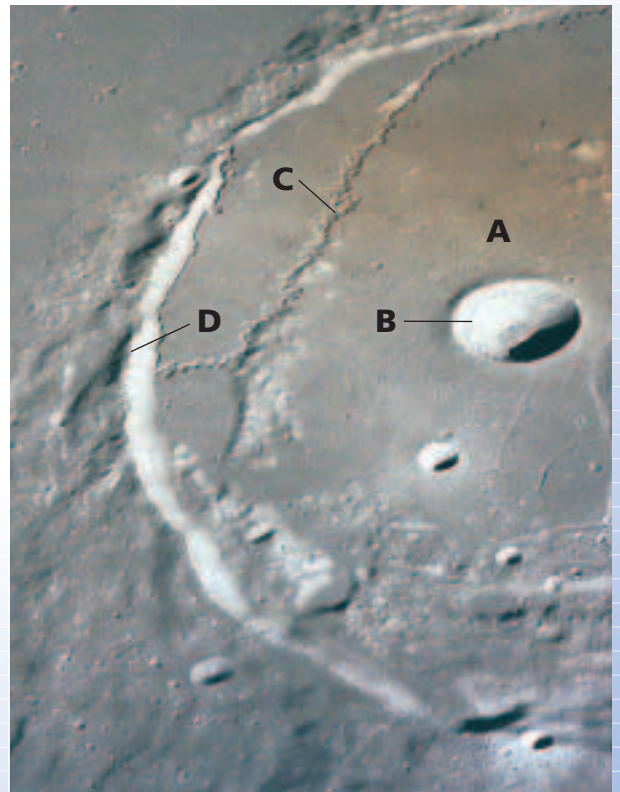
II

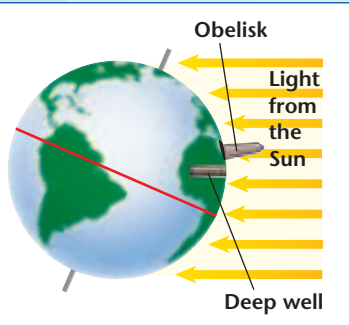


III



IV





The Size of Earth

We know that Earth is round, but how do we know how large it really is? Have you ever wondered how we measure such a large object? Long ago, before the development of high-tech computers and space shuttles, one man used his knowledge of geometry to determine the circumference of Earth.

Using Geometry

An ancient Greek mathematician, Eratosthenes (276–194 B.C.), was the first to develop a method for determining the circumference of Earth. It was known during his time that at noon on the summer solstice, when the Sun was directly overhead in Syene, Egypt, sunlight reached the bottom of a local well. However, to the north, in Alexandria, the Sun cast a shadow off an obelisk on the same day and at the same time.

Eratosthenes knew that the distance between the two cities was approximately 4900 stadia, an ancient form of measurement equivalent to 770 km by today's estimate. He measured the height of the obelisk and the length of the shadow. Then, by using the relationship

$$\arctan \left(\frac{\text{length of shadow}}{\text{height of obelisk}} \right)$$

he calculated that the Sun was 7° lower than directly overhead. Knowing that Earth was round, and that round objects have a total of 360° , Eratosthenes determined that the difference in latitude of the two cities was 7° . Because sunlight could be seen at the bottom of the well in Syene on the summer solstice, Eratosthenes determined that Syene was at latitude 23.5°N and that Alexandria was at latitude 30.5°N .

Procedure

- Using a compass and a sheet of paper, draw a diagram of Earth. Mark the equator.

- Using a protractor, locate Syene at latitude 23.5°N and Alexandria at latitude 30.5°N .
- Knowing that the difference in latitudes of the two cities is 7° and that a circle has 360° , you can determine what portion of a circle is 7° . This ratio of 7° to 360° can be represented by

$$\frac{d}{C} = \frac{7^\circ}{360^\circ}$$

where d is the distance between Alexandria and Syene, and C is Earth's circumference. Given that $d = 770$ km (4900 stadia), solve the equation for C . Then find Earth's radius using $C = 2\pi r$.

- Use your answers in step 3 to determine Earth's diameter.

Challenge

- Earth's radius is actually 6378.1 km. How do your measurements compare to this?
- What is the percent deviation of your measurement?

$$\text{Percent deviation} = \frac{\text{difference from accepted value}}{\text{accepted value}} \times 100$$



To learn more about Eratosthenes' contributions to science and math, visit the Earth Science Web Site at earthgeu.com

CHAPTER 28 Study Guide

Summary

SECTION 28.1

Tools of Astronomy



Main Ideas

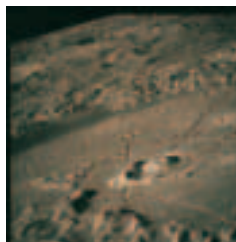
- Visible light, radio waves, infrared and ultraviolet radiation, X rays, and gamma rays are types of electromagnetic radiation.
- A telescope collects light over a large area, makes time exposures, and can use other instruments to analyze light.
- Visible-light telescopes can be made using lenses, as in refracting telescopes, or mirrors, as in reflecting telescopes.
- Space is explored by telescopes, satellites, probes, and humans.

Vocabulary

interferometry (p. 750)
reflecting telescope (p. 749)
refracting telescope (p. 749)
spinoff (p. 752)

SECTION 28.2

The Moon



Main Ideas

- The first step toward exploration of the Moon was the launch of the Soviet satellite *Sputnik 1*. The American spacecraft *Apollo 11* was the first crewed exploration of the Moon.
- The Moon's surface has many features that are not present on Earth because the Moon lacks an atmosphere and therefore its surface does not undergo erosion.
- Scientists have three theories on how the Moon formed—simultaneous formation with Earth, a passing object captured by Earth's gravity, or as the result of an object colliding with Earth. The collision theory is the most widely accepted.

Vocabulary

albedo (p. 754)
ejecta (p. 754)
highland (p. 754)
impact crater (p. 754)
mare (p. 754)
ray (p. 754)
regolith (p. 755)
rille (p. 754)

SECTION 28.3

The Sun-Earth-Moon System



Main Ideas

- The entire sky appears to rotate daily because we observe it from a rotating Earth. Our timekeeping system is based on the solar day, the length of day as observed from Earth.
- Our view of the Sun's position changes throughout the year as Earth moves in its orbit about the Sun. Seasons occur on Earth because Earth's axis is tilted.
- The Moon goes through a cycle of phases each lunar month that correspond to our changing view from Earth of the sunlit side of the Moon.
- Tides are caused by the gravitational attraction of the Moon, and to a lesser extent, the gravitational attraction of the Sun.
- A solar eclipse occurs when the Moon lies directly between Earth and the Sun. A lunar eclipse occurs when the Moon passes through Earth's shadow.

Vocabulary

apogee (p. 766)
autumnal equinox (p. 761)
ecliptic (p. 759)
lunar eclipse (p. 767)
perigee (p. 766)
solar eclipse (p. 765)
summer solstice (p. 760)
synchronous rotation (p. 764)
vernal equinox (p. 761)
winter solstice (p. 761)



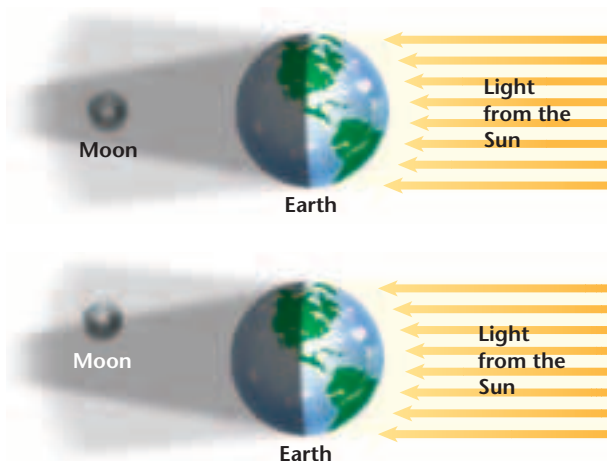
CHAPTER 28 Assessment

Understanding Main Ideas

- On what does the light-collecting power of a telescope depend?
 - the type of telescope
 - the area of the opening through which light enters
 - the location of the telescope
 - the distance from the telescope to the object being observed
- What is the same for all types of electromagnetic radiation?
 - frequency
 - wavelength
 - color
 - speed
- What type of radiation does not have to be observed above Earth's atmosphere?
 - visible light
 - X rays
 - gamma rays
 - ultraviolet radiation
- During which of the following is the Sun directly overhead at 23.5° north latitude?
 - summer solstice
 - vernal equinox
 - winter solstice
 - autumnal equinox
- Which of the following provides evidence that Earth is rotating?
 - The Sun rises and sets.
 - The plane of a Foucault pendulum appears to shift its orientation.
 - The Moon goes through phases.
 - The same side of the Moon always faces Earth.
- Which of the following is in the correct order?
 - waning crescent, third quarter, waning gibbous, new moon
 - waxing gibbous, full moon, waning gibbous, third quarter
 - new moon, waning gibbous, first quarter, waning crescent
 - waxing crescent, new moon, waning crescent, first quarter

- List the various forms of electromagnetic radiation according to wavelength, from shortest to longest.
- Why must some telescopes be launched into space?

Use the diagrams below to answer question 9.



- List the types of shadows as well as the types of eclipses that will be seen by an observer on the unlit side of Earth.
- What is electromagnetic radiation?
- How was the lunar regolith formed?
- Describe how a lunar month is defined. How long is it?
- Of all types of electromagnetic radiation, which can the human eye detect?

Test-Taking Tip

CROSSING OUT Cross out choices you've eliminated. If you can't write in the test booklet, list the answer choice letters on the scratch paper and cross them out there. You'll save time and stop yourself from choosing an answer you've mentally eliminated.

CHAPTER 28

Assessment

- How did the mountain ranges around the maria on the Moon form?
- Why are the temperature fluctuations on the surface of the Moon so extreme compared to those on Earth?

Applying Main Ideas

- What are the Moon's positions relative to the Sun and Earth when we observe a full moon and a new moon?
- Why does the Sun's altitude in the sky change throughout the year?
- If the Moon rotated twice on its axis for every one time it orbited Earth, would it be in synchronous rotation? Explain.
- Suppose the Moon's orbital plane were exactly aligned with Earth's orbital plane. How often would eclipses occur?
- Why is it best to get away from city lights to view the nighttime sky?

Thinking Critically

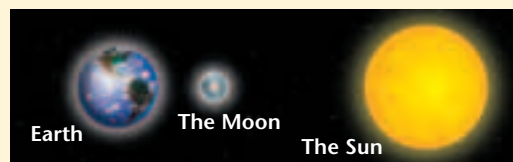
- How would Earth's surface look if Earth did not have an atmosphere?
- Why did one-half of the Moon's surface remain hidden from human sight until the era of space probes, which started in 1959?
- When observers on Earth can see a total lunar eclipse, what kind of eclipse would be seen by an observer on the Moon?
- In some maria, there are craters. Which are younger, the maria or the craters?
- How would the topography of the Moon be different if the Moon had an atmosphere?

Standardized Test Practice

- What is debris from an impact that falls back to the surface of the Moon called?
 - rilles
 - maria
 - ejecta
 - albedo
- In December, the South Pole is tilted farther toward the Sun than at any other time of the year, and the North Pole is tilted its farthest away from the Sun. What is the northern hemisphere experiencing at that time?
 - the winter solstice
 - the summer solstice
 - the vernal equinox
 - the autumnal equinox

INTERPRETING SCIENTIFIC ILLUSTRATIONS

Use the diagram below to answer questions 3 and 4.



- What results on Earth when the Sun and the Moon are aligned along the same direction, as in the diagram?
 - spring tides
 - neap tides
 - the autumnal equinox
 - the summer solstice
- If the Moon in this diagram were passing directly between the Sun and Earth, thereby blocking our view of the Sun, what would we be experiencing on Earth?
 - a lunar eclipse
 - a solar eclipse
 - umbra
 - penumbra

