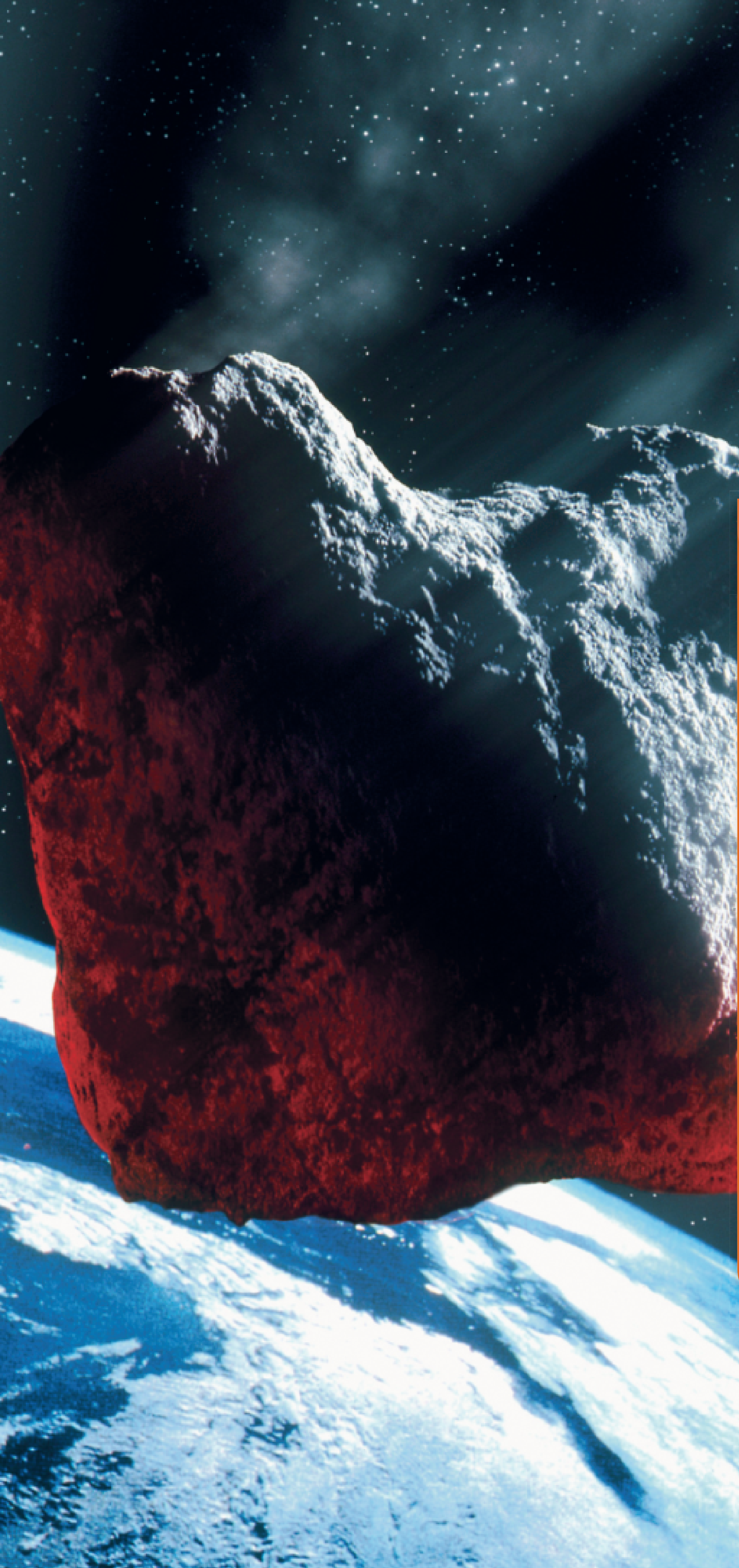
Chapter 28

Minor Bodies of the Solar System

Chapter Outline

Why It Matters

Fragments from the formation of the solar system still exist as asteroids, comets, and meteoroids. These objects could demand more than study if they came too close to Earth.



Inquiry Lab

20 min

Suit Up!

Have one partner put on **padded work gloves.** Wearing the gloves, try to open a **CD case,** take out the **CD,** and then close the case. Next, try putting on a pair of **socks** and **shoes** and tying up your **shoelaces.** Your partner will prepare a **chart** and use a **clock** to record the time to perform the tasks. Repeat all tasks without the gloves, again recording the times. Trade roles and repeat. See who can perform each task faster.

Questions to Get You Started

1. What can you infer about working in a spacesuit from this exercise?
2. How else can astronauts carry out tasks in space without having to wear spacesuits?

READING TOOLBOX

These reading tools will help you learn the material in this chapter.

Word Origins

Names of Jupiter's Moons The planet Jupiter was named for the king of the gods in Roman mythology. Jupiter's four largest moons are named after characters associated with Jupiter or Zeus (Jupiter's counterpart in Greek mythology): Io, Europa, Ganymede, and Callisto.

Your Turn The moons of many planets were named for characters in mythology and literature. As you read Section 3, add the planets' moons to a table like the one below. Use a dictionary or other sources to discover the origins of the moons' names.

Planet	Moon	Origin of name
Saturn	Titan	In Roman mythology, the sisters and brothers of Chronos (the Greek counterpart of Saturn) were the Titans. (Other moons of Saturn are named after specific Titans.)

Describing Space

Words and Phrases When you describe the motion of objects through space, you use verbs and phrases that modify the verbs. Paying attention to language that describes motion can help you recognize what kind of motion is described.

Your Turn As you read Section 2, make a three-column table like the one below. Add words or phrases that describe the motion of specific objects.

Objects	Words Describing Motion	Meaning of Motion Words
moon	rotate	spin around a central point (an axis)

Note Taking

Two-Column Notes Two-column notes can help you learn the main ideas from each section. This note-taking strategy will help you review information for quizzes and tests.

Your Turn Complete two-column notes for main ideas in Sections 1 and 4. Follow the example from Section 1 that is shown below.

1. Write one main idea in each row in the left column.
2. As you read Sections 1 and 4, add detailed notes and examples in the right column. Be sure to put these details and examples in your own words.

Main Idea	Detail Notes
The lunar surface	• several types of surface features -craters (impact depressions) - rilles (long, deep channels) -ridges (long, narrow rock elevations) -regolith (dust and small rocky fragments) -rocks

For more information on how to use these and other tools, see **Appendix A.**

SECTION 1

Earth's Moon

Key Ideas	Key Terms	Why It Matters
❯ List four kinds of lunar surface features. ❯ Describe the three layers of the moon. ❯ Summarize the three stages by which the moon formed.	**satellite** **moon** **mare** **crater**	The moon is the only body in the solar system besides Earth that humans have visited in person.

A body that orbits a larger body is called a **satellite.** Six of the planets in our solar system have smaller bodies that orbit around them. These natural satellites are also called **moons.** Our moon is Earth's natural satellite.

In 1957, the Soviet Union launched *Sputnik*, which was the first *artificial satellite* launched into space. In 1958, the United States launched its first artificial satellite, which was named *Explorer 1*. Thousands of artificial satellites are now in orbit around Earth, including weather satellites and space telescopes, such as the *Hubble Space Telescope*.

Exploring the Moon

Between 1969 and 1972, the United States sent six spacecraft to the moon as part of the Apollo space program. Apollo astronauts found that the moon's weak gravity affected the way they moved. They discovered that bouncing was more efficient than walking. Apollo astronauts also explored the moon's surface in a variety of specially-designed vehicles, such as the one shown in **Figure 1.**

The moon has much less mass than Earth does, so the gravity on the moon's surface is about one-sixth of the gravity on Earth. As a result, someone who weighs 690 N (newtons) on Earth would weigh about 115 N on the moon. (The person's mass would remain the same.) The gravity at the moon's surface is not strong enough to hold gases, so the moon has no significant atmosphere. Because it has no atmosphere to absorb and transport thermal energy, the moon's surface temperature varies from 134 °C during the day to −170 °C at night.

satellite a natural or artificial body that revolves around a celestial body that is greater in mass

moon a celestial body that revolves around a body that is greater in mass; a natural satellite

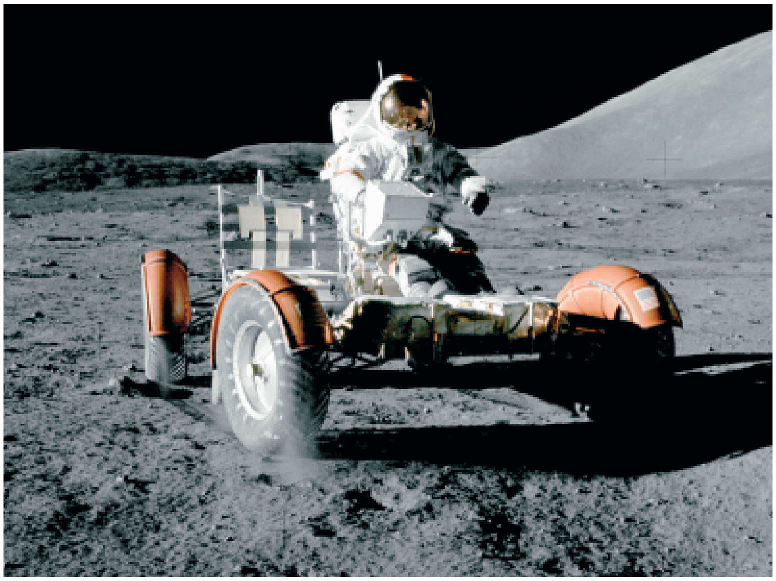


Figure 1 *Apollo 17* astronaut Eugene Cernan explores the lunar surface in a Lunar Roving Vehicle.

The Lunar Surface

Because *luna* is the Latin word for "moon," any feature of the moon is referred to as *lunar*. Light and dark patches on the moon can be seen with the unaided eye. The lighter areas are rough highlands that are composed of rocks called *anorthosites*. The darker areas are smooth, reflect less light, and are called *maria* (MAHR ee uh). Each dark area is a **mare** (MAHR AY). *Mare* is Latin for "sea." Galileo named these dark areas *maria* because he thought that they looked like Earth's seas. Today, astronomers know that maria are plains of dark, solidified, basaltic lava. These lava plains formed more than 3 billion years ago when lava slowly filled basins that were created by impacts of massive asteroids.

mare a large, dark area of basalt on the moon (plural, *maria*)

crater a bowl-shaped depression that forms on the surface of an object when a falling body strikes the object's surface or when an explosion occurs

Craters, Rilles, and Ridges

The surface of the moon, shown in **Figure 2,** is covered with numerous bowl-shaped depressions, called **craters.** Most of the moon's craters formed when debris left over from the formation of the solar system struck the moon about 4 billion years ago. Younger craters are characterized by bright streaks, called *rays*, that extend outward from the impact site. Even these younger craters, however, are almost all billions of years old.

Long, deep channels called *rilles* run through the maria in some places. The moon's rilles are thought to be leftover lava channels from the formation of the maria. Some rilles are as long as 240 km. Another surface feature of the moon is ridges. Ridges are long, narrow elevations of rock that rise out of the surface and criss-cross the maria.

Reading Check **Name two features of the moon.** (See Appendix G for answers to Reading Checks.)

Academic Vocabulary

depression (dee PRESH uhn) an area lower than the surrounding surface

READING TOOLBOX

Describing Space

As you read Section 1, make a table like the one described at the beginning of the chapter to describe motion words. In the left column, list objects. In the middle column, list verbs (and the phrases the modify them) that describe the motion of the objects. In the right column, state the meaning of the motion words.

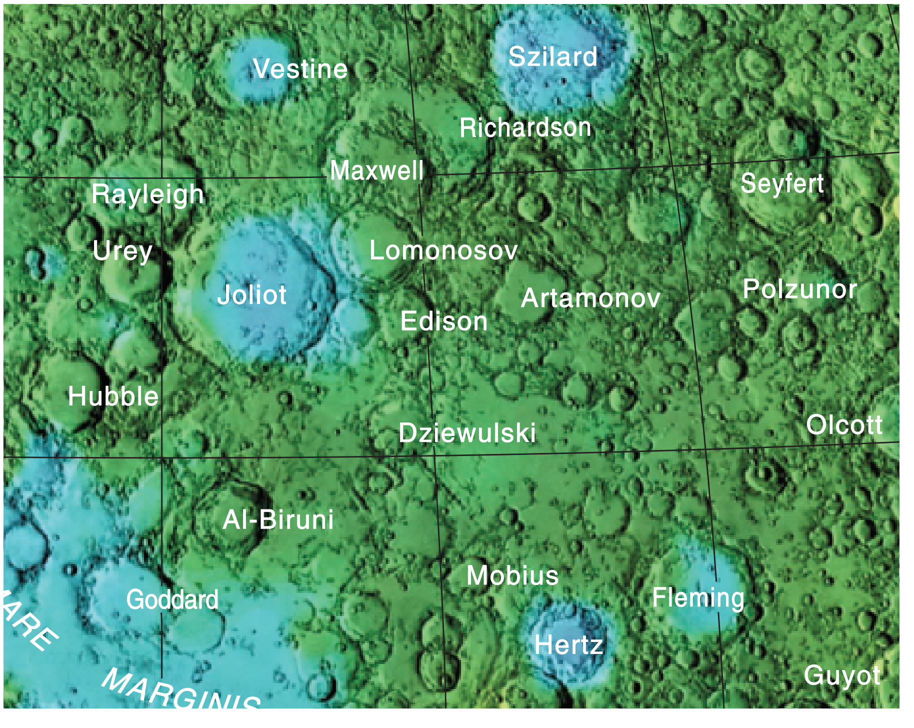


Figure 2 More than 1,500 craters on the moon are named for scientists, scholars, and other noteworthy individuals. The lunar surface also has millions of small, overlapping craters. ***How does the size of a crater relate to the importance of the individual for which it was named?***

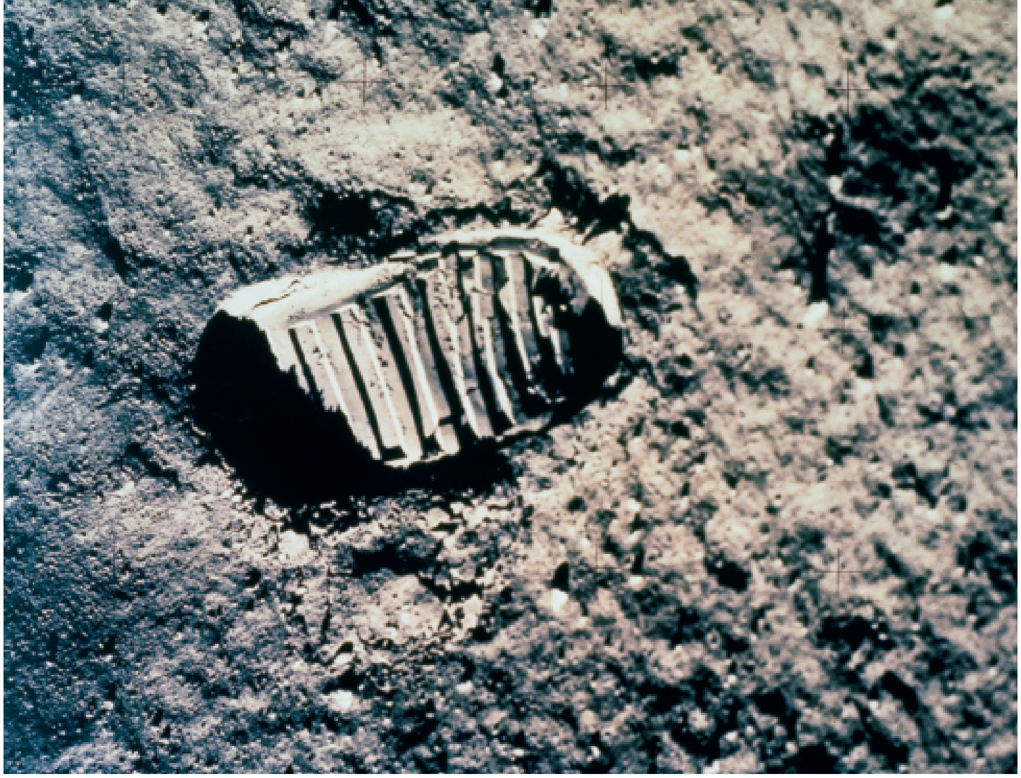


Figure 3 This footprint from an Apollo astronaut is one of the first marks left on the moon by humans. The footprint is visible because of the fine layer of rock and dust, called *regolith*, that covers the moon's surface.

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Regolith

More meteorites have reached the surface of the moon than have reached Earth's surface because the moon has no atmosphere for protection. Over billions of years, these meteorites crushed much of the rock on the lunar surface into dust and small fragments. Today, almost all of the lunar surface is covered by a layer of dust and rock, called *regolith*. Regolith is shown in **Figure 3.** The depth of the regolith layer varies from 1 m to 6 m.

Lunar Rocks

Many lunar rocks are very similar to rocks on Earth. Lunar rocks, including the one shown in **Figure 4,** contain many of the same elements as Earth's rocks do, but lunar rocks contain different proportions of those elements. Lunar rocks are igneous, and most rocks near the surface are composed mainly of oxygen and silicon. These surface rocks are similar to the rocks in Earth's crust. Rocks from the lunar highlands are light-colored, coarse-grained anorthosites. Highland rocks are rich in calcium and aluminum. Rocks from the maria are fine-grained basalts and contain large amounts of titanium, magnesium, and iron.

Nevertheless, lunar surface rocks have only small amounts of some elements that are common on Earth. Many of these elements have low melting points and may have boiled off early in the moon's history when the moon was still molten. Also, the minerals in lunar rocks do not contain water.

One type of rock that occurs in both maria and the highlands is *breccia*. Lunar breccia contains fragments of other rocks that have been fused together. These breccias formed when meteorites struck the moon. The force of these impacts broke up rocks, and the heat from the impacts partially melted the fragments.

Figure 4 This rock is 4.3 billion to 4.5 billion years old; it is the oldest rock discovered on the moon. The rock's texture indicates that the rock has a complicated history.

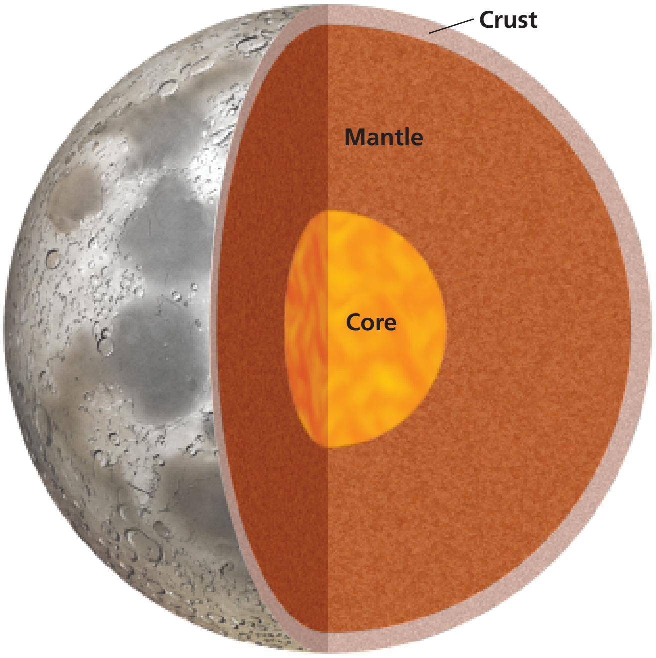


Figure 5 The moon, like Earth, has three compositional layers: the crust, the mantle, and the core.

The Interior of the Moon

Rocks of the lunar surface are about as dense as those on Earth's surface. However, the overall density of the moon is only three-fifths the density of Earth. The difference in overall density indicates that the interior of the moon is less dense than the interior of Earth.

Most of the information about the interior of the moon comes from seismographs that were placed on the moon by the Apollo astronauts. Seismographs recorded numerous weak moonquakes, which are similar to earthquakes. More than 10,000 moonquakes have been detected. Most moonquakes occur in the mantle at a depth that is 10 times deeper than the depth at which most earthquakes occur on Earth. From these moonquakes, scientists learned that the moon's interior is layered, as shown in **Figure 5.**

Quick Lab

5 min

Liquid and Solid Cores

Procedure

1. Take one uncooked egg and one hardboiled egg. With your thumb and forefinger, spin both eggs.
2. Record the amount of time each egg spins.
3. Lay one can of solid food and one can of soup on their sides, and spin both cans.
4. Record the amount of time each can spins.

Analysis

1. Which egg stopped spinning first? Which can of food stopped spinning first?
2. Which rotates more steadily: an object that has a solid core or an object that has a liquid core? Explain your answer.

The Moon's Crust

One side of the moon always faces Earth. That side is therefore called the *near side*. The other side always faces away from Earth and is called the *far side*. The pull of Earth's gravity during the moon's formation caused the crust on the far side of the moon to become thicker than the crust on the near side. On the near side, the lunar crust is about 60 km thick. On the far side, the lunar crust is up to 100 km thick. Images of the far side show that the far side's surface is mountainous and has only a few small maria. The crust of the far side appears to consist of materials that are similar to those of the rocks in the highlands on the near side.

Reading Check **Name two features of the far side of the moon.**

The Moon's Mantle and Core

Beneath the crust is the moon's mantle. The mantle is thought to be made of rock that is rich in silica, magnesium, and iron. Of the moon's 1,738 km radius, the mantle makes up more than half of that distance and reaches 1,000 km below the crust.

Scientists think that the moon has a small iron core that has a radius of less than 700 km. When laser beams were bounced off small mirrors placed on the moon, scientists discovered that the moon's rotation is not uniform. This non-uniform rotation indicates that the core is neither completely solid nor completely liquid. This characteristic may explain why the moon has almost no overall magnetic field. There are, however, small areas on the moon that exhibit local magnetism.

The Formation of the Moon

Rocks taken from the moon by Apollo astronauts provided evidence to help astronomers understand the moon's history. Most scientists generally agree that the moon formed in three stages.

The Giant Impact Hypothesis

Most scientists think that the moon's development began when a large object collided with Earth more than 4 billion years ago. This *giant impact hypothesis* states that a Mars-sized body struck Earth early in the history of the solar system. Before the impact, Earth was molten, or heated to an almost liquid state. The collision ejected chunks of Earth's mantle into orbit around Earth. The debris eventually clumped together to form the moon, as shown in **Figure 6.**

Most of the ejected materials came from Earth's silica-rich mantle rather than from Earth's dense, metallic core. This hypothesis explains why moon rocks share many of the chemical characteristics of Earth's mantle. As the material clumped together, it continued to revolve around Earth because of Earth's gravitational pull.

Differentiation of the Lunar Interior

Early in its history, the lunar surface was covered by an ocean of molten rock. Over time, the densest materials moved toward the center of the moon and formed a small core. The least dense materials formed an outer crust. The other materials settled between the core and the outer layer to form the moon's mantle.

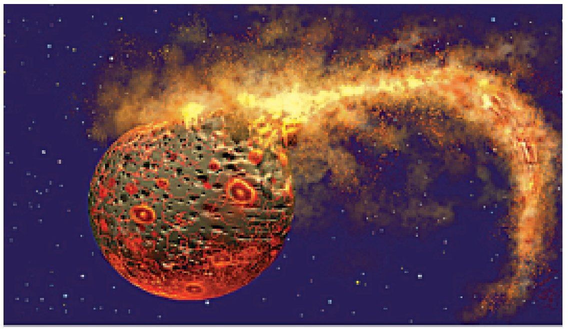
Meteorite Bombardment

The outer surface of the moon eventually cooled to form a thick, solid crust over the molten interior. At the same time, debris left over from the formation of the solar system struck the solid surface and produced craters and regolith.

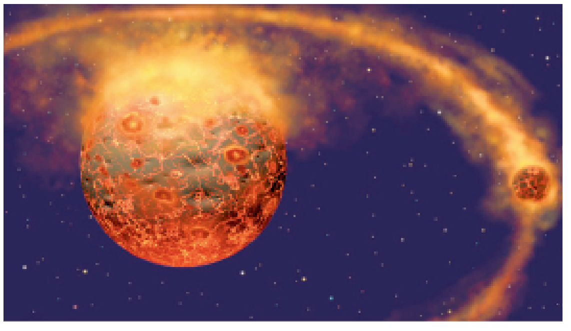
About 3 billion years ago, the number of small objects in the solar system decreased. Less material struck the lunar surface, and few new craters formed. Craters that have rays formed during the most recent meteor impacts. During this stage of lunar development, virtually all geologic activity stopped. Because the moon cooled more than 3 billion years ago, it looks today almost exactly as it did 3 billion years ago. Therefore, the moon is a valuable source of information about the conditions that existed in the solar system long ago.

Figure 6 **The First Stage of Moon Formation**

Scientists think that a Mars-sized object collided with Earth and blasted part of Earth's mantle into space.



The resulting debris then began to revolve around Earth.



The material eventually joined to form Earth's moon.

Figure 7 The near side of the moon (top) has fewer visible craters than the far side (bottom) does in part because lava flows on the near side covered many of the impact sites with maria.

Lava Flows on the Moon

After impacts on the moon's surface formed deep basins, lava flowed out of cracks, or *fissures,* in the lunar crust. This lava flooded the crater basins to form maria. The presence of the maria suggests that fissure eruptions once characterized the moon, even though there is no evidence that large active volcanoes have ever been present on the moon.

Because the moon's crust is thinner on the near side than on the far side, much more lava flowed onto the surface on the near side than onto the surface of the far side of the moon. The near side of the moon has several smooth maria, but the far side has few maria and many more craters, as shown in **Figure 7.**

Scientists do not yet know how magma formed in the lunar interior or how the magma reached the surface. There is no evidence of plate tectonics or convection currents in the moon's mantle, so the magma must have formed in some other way. A large amount of energy would have been needed to produce the magma in the upper layers of the moon. Some scientists think this energy may have come from a long period of intense meteorite bombardment. Other scientists think that radioactive decay of materials may have also heated the moon's interior enough to cause magma to form. Scientists agree that the lava flows ended about 3.1 billion years ago, when the interior cooled completely.

Section 1 Review

Key Ideas

1. **Describe** what maria on the surface of the moon look like and how they came to be known as maria.
2. **Compare** the thickness of the moon's crust on the near side with the thickness of the crust on the far side.
3. **Summarize** how and when the maria formed.
4. **Describe** how the surface of the moon would be different today if meteorites had continued to hit it at the same rate as they did 3 billion years ago.
5. **Describe** breccias and how they formed on the moon.
6. **Summarize** how scientists think the moon formed.

Critical Thinking

7. **Analyzing Ideas** Explain how Earth's gravity affected the moon's near side and far side differently.
8. **Making Comparisons** Compare the features of the lunar surface created by lava flows and the features created by impacts.

Concept Mapping

9. Use the following terms to create a concept map: *moon, meteorite, crater, rille, maria, highlands,* and *basalt.*

SECTION 2

Movements of the Moon

Key Ideas	Key Terms	Why It Matters
❯ Describe the shape of the moon's orbit around Earth. ❯ Explain why eclipses occur. ❯ Describe the appearance of four phases of the moon. ❯ Explain how the movements of the moon affect tides on Earth.	**apogee** **perigee** **eclipse** **solar eclipse** **lunar eclipse** **phase**	Understanding the movements of the moon enables us to predict solar and lunar eclipses as well as low and high tides.

If you looked down on the moon from above its north pole, you would see the moon rotate once on its axis every 27.3 days. However, if you stood on the moon's surface and measured the lunar day by the amount of time between sunrises, you would find that a lunar day is 29.5 Earth days long. This discrepancy is due to the fact that, while the moon is revolving around Earth, Earth and the moon are also revolving around the sun.

The Earth-Moon System

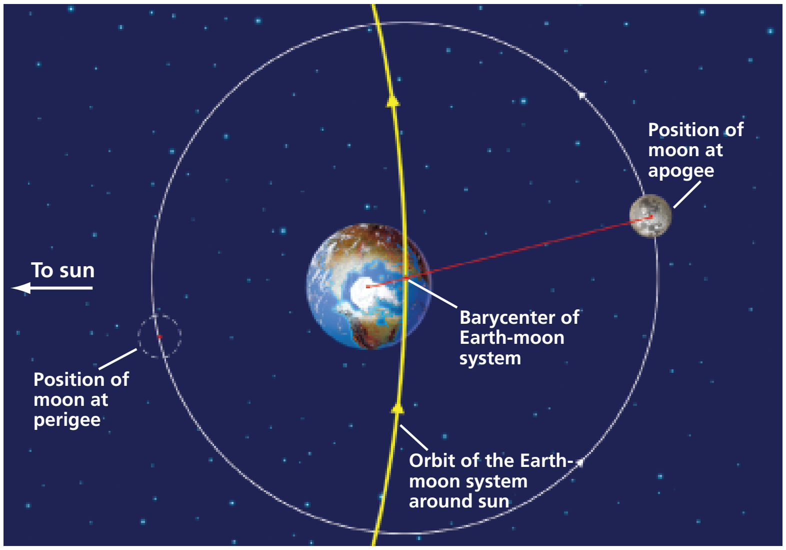
To observers on Earth, the moon appears to orbit Earth. However, if you could observe Earth and the moon from space, you would see that Earth and the moon revolve around each other. Together, they form a single system that orbits the sun.

The mass of the moon is only 1/80 that of Earth. So, the balance point of the Earth-moon system is not halfway between the centers of the two bodies. The balance point is located within Earth's interior because Earth's mass is greater than the moon's mass. This balance point is called the *barycenter*. The barycenter follows a smooth orbit around the sun, as shown in **Figure 1.**

apogee in the orbit of a satellite, the point that is farthest from Earth

perigee in the orbit of a satellite, the point that is closest to Earth

Figure 1 The Earth-moon system.



The Moon's Elliptical Orbit

The orbit of the moon around Earth forms an ellipse that is about 5% more elongated than a circle is. Therefore, the distance between Earth and its moon varies over a month's time. When the moon is farthest from Earth, the moon is at **apogee.** When the moon is closest to Earth, the moon is at **perigee.** The average distance of the moon from Earth is 384,000 km.

Moonrise and Moonset

The moon appears to rise and set at Earth's horizon because of Earth's rotation on its axis. If you were to watch the moon rise or set on successive nights, however, you would notice that it rises or sets approximately 50 minutes later each night. This happens because of both Earth's rotation and the moon's revolution. While Earth completes one rotation each day, the moon also moves in its orbit around Earth. It takes an extra 1/29 of Earth's rotation, or 50 minutes, for the horizon to catch up to the moon.

Academic Vocabulary

successive (suhk SES iv) following one after the other; consecutive

Lunar Rotation

In addition to orbiting Earth and revolving around the sun, the moon also spins on its axis. The moon rotated rapidly when it formed, but the pull of Earth's gravity has slowed the moon's rate of rotation. The moon now spins very slowly and completes a rotation only once during each orbit around Earth. The moon revolves only once around Earth in about 27.3 days relative to the stars. Because the rotation and the revolution of the moon take the same amount of time, observers on Earth always see the same side of the moon. Therefore, images of the far side of the moon must be taken by spacecraft orbiting the moon.

As the moon orbits Earth, the part of the moon's surface that is illuminated by sunlight changes. The sun's light always illuminates half of the moon and, as shown in **Figure 2,** half the Earth. The near side of the moon is sometimes fully illuminated by the sun. At other times, depending on where the moon is in its orbit, the near side is partly or completely darkened.

READING TOOLBOX

Two-Column Notes

Create two-column notes to review the main ideas for Section 2. Put the main ideas in the left column, and add details and examples in your own words in the right column. Use as a model the two-column notes table that you started at the beginning of the chapter.

Reading Check **Why are we unable to photograph the far side of the moon from Earth?**

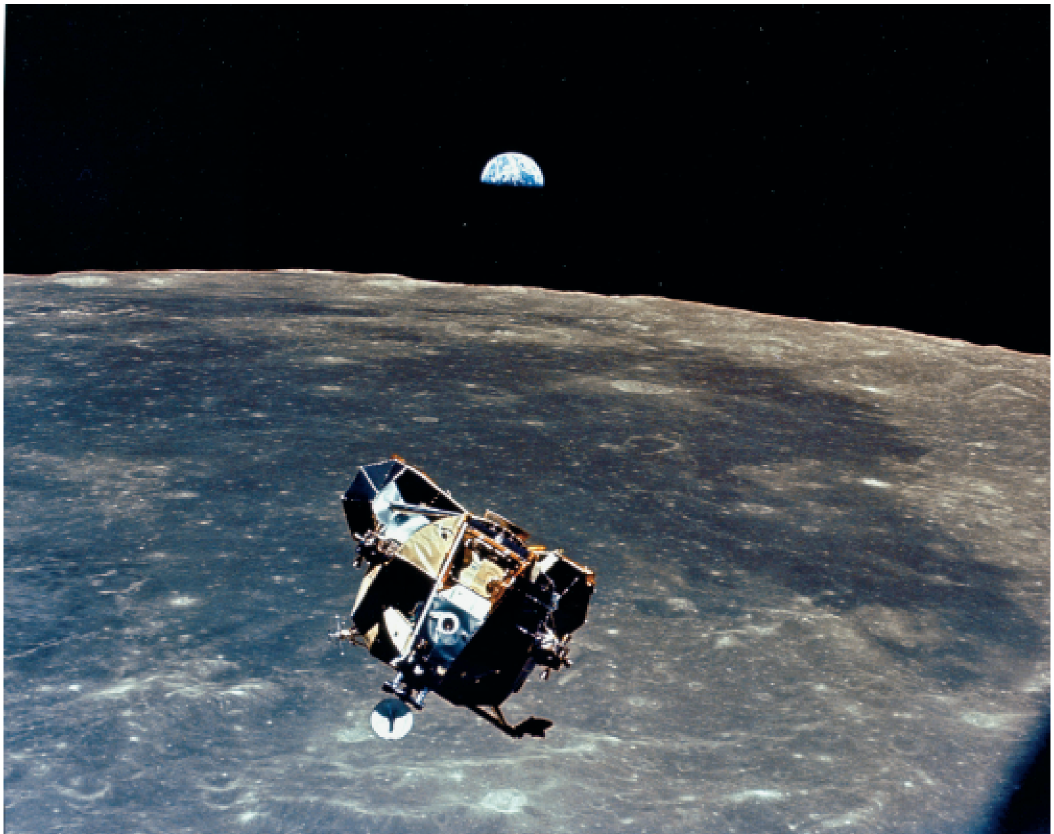


Figure 2 The lunar landing module, which was also called *The Eagle*, flew to meet the command module at the end of the *Apollo 11* mission. Seen from this viewpoint, Earth is illuminated from above.

Figure 3 During a solar eclipse, the shadow of the moon falls on Earth. The distance between Earth and the moon in this diagram is not to scale.

Eclipses

Bodies orbiting the sun, including Earth and its moon, cast long shadows into space. An **eclipse** occurs when one celestial body passes through the shadow of another. Shadows cast by Earth and the moon have two parts. In the inner, cone-shaped part of the shadow, the *umbra*, sunlight is completely blocked. In the outer part of the shadow, the *penumbra*, sunlight is only partially blocked, as shown in **Figure 3.**

eclipse an event in which the shadow of one celestial body falls on another

solar eclipse the passing of the moon between Earth and the sun; during a solar eclipse, the shadow of the moon falls on Earth

Solar Eclipses

When the moon is directly between the sun and part of Earth, the shadow of the moon falls on Earth and causes a **solar eclipse.** During a *total solar eclipse*, the sun's light is completely blocked by the moon. The umbra falls on the area of Earth that lies directly in line with the moon and the sun. Outside the umbra, but within the penumbra, people see a *partial solar eclipse*. The penumbra falls on the area that immediately surrounds the umbra.

The umbra of the moon is too small to make a large shadow on Earth's surface. The part of the umbra that hits Earth during an eclipse, as shown in **Figure 4,** is never more than a few hundred kilometers across. So, a total eclipse of the sun covers only a small part of Earth and is seen only by people in particular parts of Earth along a narrow path. A total solar eclipse also never lasts more than about seven minutes at any one location. A total eclipse will not be visible in the United States until 2017, even though there is a total eclipse somewhere on Earth about every 18 months.

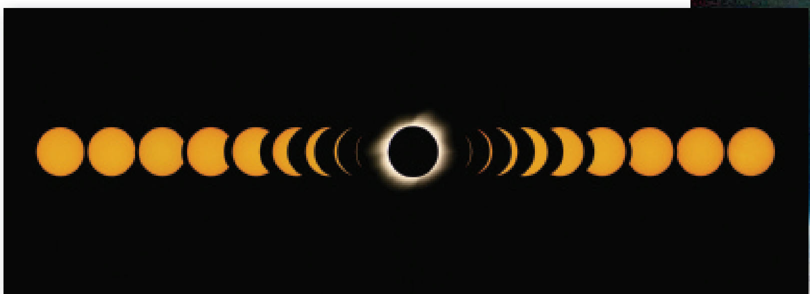


Figure 4 The dark area (right) is the shadow of the moon cast on cloudtops over Europe during a total solar eclipse in 1999. The photo was taken from the orbiting space station *Mir*. The composite (above) shows the partial and total phases of a solar eclipse over several hours.

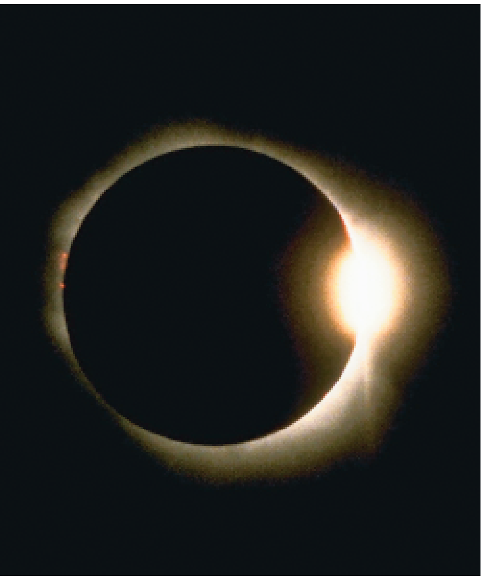


Figure 5 The diamond-ring effect produced by a solar eclipse can be stunning for observers on the part of Earth that falls under the moon's shadow.

Effects of Solar Eclipses

During a total solar eclipse, people on the ground are in the moon's umbra. In the areas on Earth's surface under the umbra, the sky becomes as dark as it does at twilight. During this period of darkness, the sunlight that is not eclipsed by the moon shows the normally invisible outer layers of the sun's atmosphere. The last bits of normal sunlight before darkness often glisten like the diamond on a ring and cause what is known as the *diamond-ring effect*. The diamond-ring effect is shown in **Figure 5.** Therefore, many people think that total solar eclipses are very beautiful.

If the moon is at or near apogee when it comes directly between Earth and the sun, the moon's umbra does not reach Earth. If the umbra fails to reach Earth, a ring-shaped eclipse occurs. This type of eclipse is called an *annular eclipse*, because *annulus* is the Latin word for "ring." During an annular eclipse, the sun is never completely blocked out. Instead, a thin ring of sunlight is visible around the outer edge of the moon. The brightness of this thin ring of ordinary sunlight prevents observers from seeing the outer layers of the sun's atmosphere that are visible during a total solar eclipse. An annular eclipse will be visible from the American Southwest on May 20, 2012.

Reading Check **What is one difference between a total solar eclipse and an annular eclipse?**

Quick Lab Eclipses

15 min

Procedure

1. Make two balls from modeling clay, one about 4 cm in diameter and one about 1 cm in diameter.
2. Using a metric ruler, position the balls about 15 cm apart on a sheet of paper, as shown in the photo at right.
3. Turn off any nearby lights. Place a penlight approximately 15 cm in front of and almost level with the larger ball. Shine the light on the larger ball. Sketch your model, and note the effect of the beam of light.
4. Repeat step 3, but reverse the positions of the two balls. You may need to raise the smaller ball slightly to center its shadow on the larger ball. Sketch your model, and again note the effect of the light beam.

Analysis

1. Which planetary bodies do the larger clay ball, the smaller clay ball, and the penlight represent?
2. As viewed from Earth, what event did your model in step 3 represent? As viewed from the moon, what would your model represent?
3. As viewed from Earth, what event did your model in step 4 represent? As viewed from the moon, what would your model represent?
4. In what ways could you modify this activity to more closely model how eclipses occur?

Figure 6 During a lunar eclipse, the shadow of Earth falls on the moon. The distance between Earth and the moon in this diagram is not to scale.

Lunar Eclipses

A **lunar eclipse** occurs when Earth is positioned between the moon and the sun and when Earth's shadow crosses the lighted half of the moon. For a total lunar eclipse to occur, the entire moon must pass into Earth's umbra, as shown in **Figure 6.** When only part of the moon passes into Earth's umbra, a *partial lunar eclipse* occurs. The remainder of the moon passes through Earth's penumbra. When the entire moon passes through Earth's penumbra, a *penumbral eclipse* occurs. During a penumbral eclipse, the moon darkens so little that the eclipse is barely noticeable.

lunar eclipse the passing of the moon through Earth's shadow at full moon

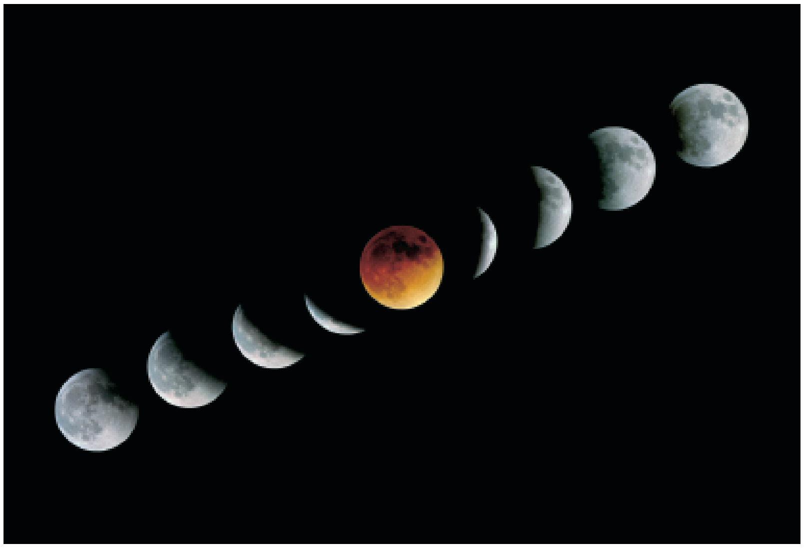
A lunar eclipse lasts for several hours. Even during a total lunar eclipse, sunlight is bent around Earth through our atmosphere. Mainly red light reaches the moon, so the totally eclipsed moon appears to have a reddish color, as shown in the middle portion of the composite image in **Figure 7.**

Frequency of Solar and Lunar Eclipses

As many as seven eclipses may occur during a calendar year. Four may be lunar, and three may be solar or vice versa. However, total eclipses of the sun and the moon occur infrequently. Solar and lunar eclipses do not occur during every lunar orbit. This is because the orbit of the moon is not in the same plane as the orbit of Earth around the sun. The moon crosses the plane of Earth's orbit only twice in each revolution around Earth. A solar eclipse will occur only if this crossing occurs when the moon is between Earth and the sun. If this crossing occurs when Earth is between the moon and the sun, a lunar eclipse will occur.

Lunar eclipses are visible everywhere from the dark side of Earth. A total solar eclipse, however, can be seen only by observers in the small path of the moon's shadow as it moves across Earth's lighted surface. A partial solar eclipse can be seen for thousands of kilometers on either side of the path of the umbra.

Figure 7 This composite image shows a total lunar eclipse as seen from Earth over several hours.



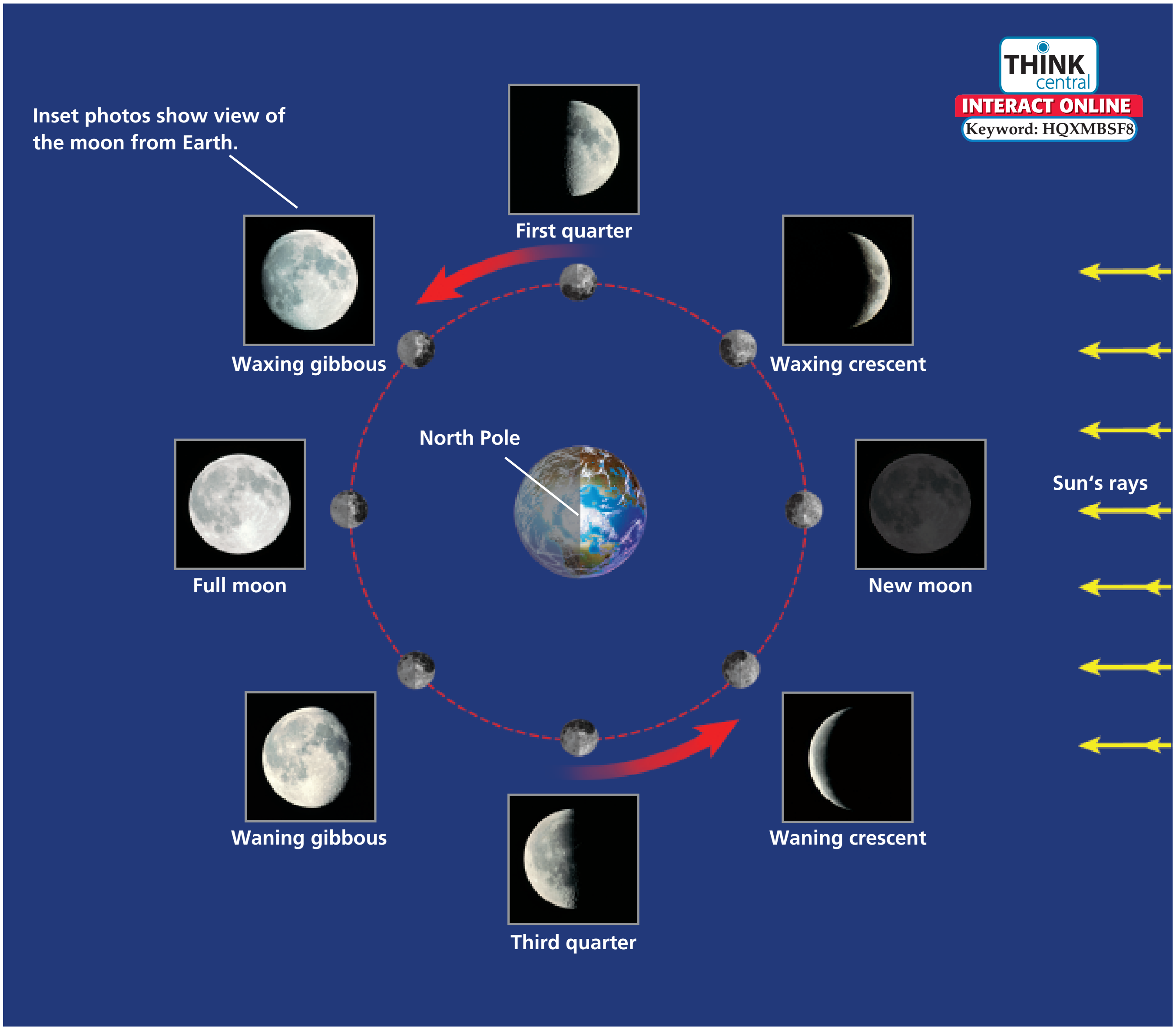
Phases of the Moon

phase the change in the illuminated area of one celestial body as seen from another celestial body; phases of the moon are caused by the changing positions of Earth, the sun, and the moon

On some nights, the moon shines brightly enough for you to read a book by its light. But moonlight is not produced by the moon. The moon merely reflects light from the sun. Because the moon is spherical, half of it is always lit by sunlight. As the moon revolves around Earth, however, different amounts of the near side of the moon, which faces Earth, are lighted. Therefore, the apparent shape of the visible part of the moon varies. These varying shapes, lighted by reflected sunlight, are called **phases** of the moon and are shown in **Figure 8.**

When the moon is directly between the sun and Earth, the sun's rays strike only the far side of the moon. As a result, the entire near side of the moon is dark. When the near side is dark, the moon is said to be in the *new-moon* phase. During this phase, no lighted area of the moon is visible from Earth.

Figure 8 Phases of the Moon



Waxing Phases of the Moon

As the moon continues to move in its orbit around Earth, part of the near side becomes illuminated. When the size of the lighted part of the moon is increasing, the moon is said to be *waxing*. When a sliver of the moon's near side is illuminated, the moon enters its *waxing-crescent* phase.

When the moon has moved through one-quarter of its orbit after the new moon phase, the moon appears to be a semicircle. Half of the near side of the moon is lighted. When a waxing moon becomes a semicircle, the moon enters its *first-quarter* phase. When the lighted part of the moon's near side is larger than a semicircle and still increasing in size, the moon is in its *waxing-gibbous* phase. The moon continues to wax until it appears as a full circle. At *full moon*, Earth is between the sun and the moon. Consequently, the entire near side of the moon is illuminated by the light of the sun.

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Topic: Lunar Cycle
Code: **HQX0887**

Waning Phases of the Moon

After the full moon phase, when the lighted part of the near side of the moon appears to decrease in size, the moon is *waning*. When it is waning but the lighted part is still larger than a semicircle, the moon is in the *waning-gibbous* phase. When the lighted part of the near side becomes a semicircle, the moon enters the *third-quarter* phase. When only a sliver of the near side is visible, the moon enters the *waning-crescent* phase. After the waning-crescent phase, the moon again moves between Earth and the sun. The moon once more becomes a new moon, and the cycle of phases begins again.

Before and after a new moon, only a small part of the moon shines brightly. However, the rest of the moon is not completely dark. It shines dimly from sunlight that reflects first off Earth's clouds and oceans and then reflects off the moon. Sunlight that is reflected off Earth is called *earthshine*. The darker part of the moon shown in **Figure 9** is lit by earthshine.

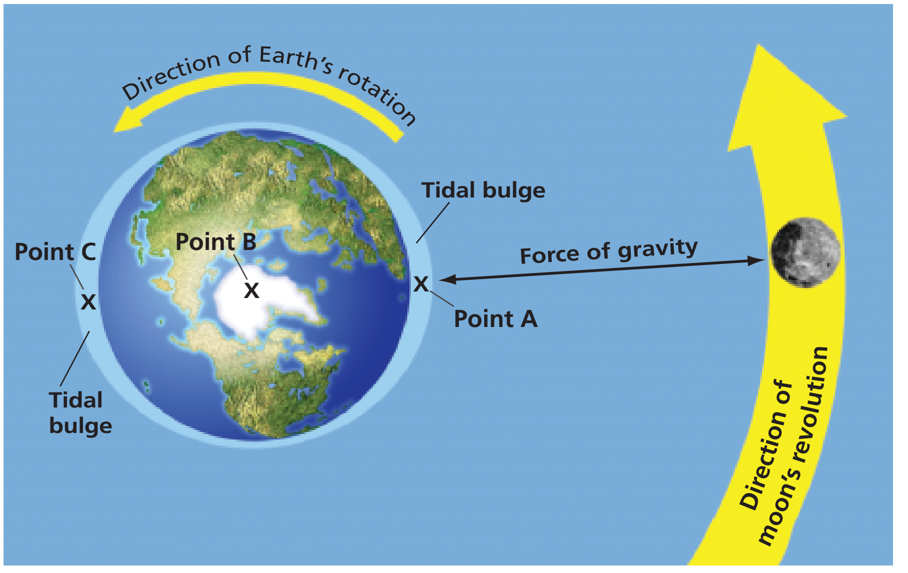
Figure 9 The darker portion of this crescent moon is not completely dark because some sunlight is reflected from Earth, to the moon, and back to Earth.

Time from New Moon to New Moon

Although the moon revolves around Earth in 27.3 days, a longer period of time is needed for the moon to go through a complete cycle of phases. The period from one new moon to the next one is 29.5 days. This difference of 2.2 days results from the orbiting of the Earth-moon system around the sun. In the 27.3 days in which the moon orbits Earth, the two bodies move slightly farther along their orbit around the sun. Therefore, the moon must go a little farther to be directly between Earth and the sun. About 2.2 days are needed for the moon to travel this extra distance. The position directly between Earth and the sun is the position of the moon in each new moon phase.

Reading Check **Describe two phases of the waning moon.**

Figure 10 The moon's pull on Earth is greatest at point A, on Earth's near side, and weakest at point C, on Earth's far side. Point B represents Earth's center of mass. Earth's rotation causes two low tides and two high tides each day on most shorelines.



Tides on Earth

Bulges in Earth's oceans, called tidal bulges, form because the moon's gravitational pull on Earth decreases with distance. Thus, the ocean on Earth's near side is pulled toward the moon with the greatest force. The solid Earth, which acts as though all of its mass were its center, experiences less force. The ocean on the far side is subject to less force than the solid Earth is. As shown in **Figure 10,** these differences cause tidal bulges. Because Earth rotates, tides occur regularly at any given point on the surface each day. The sun also causes tides, but they are smaller because the sun is much farther from Earth than the moon is. Twice each month, when the sun, moon, and Earth are almost in line, the gravitational pulls combine to produce especially high tides.

Section 2 Review

Key Ideas

1. **Explain** why the moon rises and sets about 50 minutes later each successive night.
2. **Describe** what causes a total solar eclipse.
3. **Explain** why a lunar eclipse does not occur every time the moon revolves around Earth.
4. **Summarize** how a solar eclipse differs from a lunar eclipse.
5. **Describe** the relative locations of the sun, Earth, and the moon during a new moon phase.
6. **Describe** how the appearance of the moon changes when it is waxing.
7. **Explain** why the moon repeats phases every 29.5 days but completes an orbit in 27.3 days.
8. **Explain** how the moon causes tidal bulges on Earth.

Critical Thinking

9. **Analyzing Ideas** Explain why observers on Earth always see the same side of the moon.
10. **Making Comparisons** Explain why more people see each total lunar eclipse than each total solar eclipse.
11. **Analyzing Relationships** The sun's gravity also affects tides on Earth. Why does the moon have a larger effect on tides than the sun does?

Concept Mapping

12. Use the following terms to create a concept map: *Earth, moon, sun, eclipse, solar eclipse, lunar eclipse, umbra,* and *penumbra.*

SECTION 3

Satellites of Other Planets

Key Ideas	Key Terms	Why It Matters
❯ Compare the characteristics of the two moons of Mars. ❯ Describe how volcanoes were discovered on Io. ❯ Name one distinguishing characteristic of each of the Galilean moons. ❯ Compare the characteristics of the rings of Saturn with the rings of the other outer planets.	**Galilean moon**	Studying the moons of other planets helps scientists better understand our own moon as well as the forces that have helped to shape the solar system.

Until the 1600s, astronomers thought that Earth was the only planet that had a moon. In 1610, Galileo discovered four moons orbiting Jupiter. He also observed what later were identified as the rings of Saturn. Since the time of Galileo, astronomers have discovered that all of the planets in our solar system except Mercury and Venus have moons. In addition, the gas giants Saturn, Jupiter, Uranus, and Neptune all have rings.

Moons of Mars

Mars has two tiny moons, named Phobos and Deimos. They revolve around Mars relatively quickly. Phobos and Deimos are irregularly shaped chunks of rock and are thought to be captured asteroids. Phobos is 27 km across at its longest, and Deimos is about 15 km across at its longest.

The surfaces of Phobos and Deimos are dark, like maria on Earth's moon. Both moons have many craters. The large number of craters shows that the moons have been hit by many asteroids and comets, and suggests that the moons are fairly old.

Galilean moon any one of the four largest satellites of Jupiter—Io, Europa, Ganymede, and Callisto—that were discovered by Galileo in 1610

Moons of Jupiter

Galileo observed four large moons revolving around Jupiter. Since that discovery was made, scientists have observed dozens of smaller moons around Jupiter. Smaller moons continue to be discovered today. Most of Jupiter's moons have diameters of less than 200 km, but of the largest four, known as the **Galilean moons,** three are bigger than Earth's moon. Until spacecraft flew near the moons, scientists knew little about them. Now, scientists have identified many unique characteristics of the Galilean moons. One of the four Galilean moons is shown in **Figure 1.**

Figure 1 The stormy surface of Jupiter is visible in the background. In the foreground is Io, which orbits Jupiter once every 42 hours.

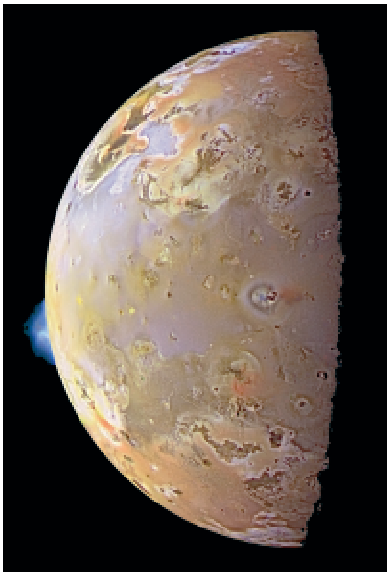


Figure 2 In this image taken by the *Galileo* spacecraft you can see a volcanic eruption on the left side of Io against the background of space.

Academic Vocabulary

extraterrestrial (eks truh tuh RES tree uhl) not of Earth

Io

Io is the innermost of Jupiter's four Galilean moons. An engineer examining images from the *Voyager* spacecraft discovered volcanoes on Io. Io is the first extraterrestrial body on which active volcanoes have been seen. Since the discovery of Io's volcanoes, scientists realize that volcanism is more widespread in the solar system than they had thought. Volcanoes on Io eject thousands of metric tons of material each second. The lava that erupts on Io is much hotter than the lava that erupts on Earth. The temperature of the lava on Io is higher because the lava has more magnesium and iron than lava on Earth does. Plumes of volcanic material on Io reach heights of hundreds of kilometers, as shown in **Figure 2.** Because parts of Io's surface are yellow-red, scientists think that the volcanic material is mostly sulfur and sulfur dioxide.

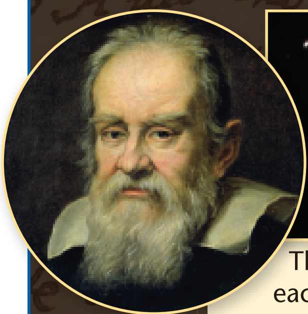
Io moves inward and outward in its orbit around Jupiter because of the gravitational pull of the other moons of Jupiter. This movement produces differences in gravitational pull on opposite sides of the moon called *tidal forces.* These forces are similar to tides on Earth caused by the pull of the moon. As Io is pulled back and forth, its surface also moves in and out. Calculations show that tidal forces make Io's surface move in and out by 100 m. Heat from the friction caused by this surface flexing results in the melting of the interior of Io and leads to volcanism. Data from the *Galileo* spacecraft show that Io has a giant iron core and may possess a magnetic field. Much of what we know about Jupiter's moons came from information gathered by the *Galileo* spacecraft, which orbited Jupiter from 1995 to 2003.

Why It Matters

HISTORY IN SCIENCE

Early Telescope Images

To the unaided eye, the only moon visible from Earth is our own. Imagine the surprise about 400 years ago when the Italian scientist and inventor, Galileo Galilei, turned his newly improved telescope to Jupiter and discovered four more moons.



The four objects changed position each night but stayed close to Jupiter. He concluded that they must be moons.

The telescope was invented in the late 1500s. In 1610, with this improved model, Galileo discovered Jupiter's largest moons.

YOUR TURN

ONLINE RESEARCH

How many moons orbit Jupiter now? Why would the number keep changing?

Europa

Europa is the second closest Galilean moon to Jupiter. Europa is about the size of Earth's moon and it is slightly less dense than Earth's moon. Astronomers think that Europa has a rock core that is covered with a crust of ice that is about 100 km thick. Images of Europa, such as the one shown in **Figure 3,** show cracks in this enormous ice sheet.

Scientists have concluded from observations made from spacecraft that an ocean of liquid water may exist under this blanket of ice. If liquid water exists, simple forms of life could also exist there. Astronomers have no evidence of life on Europa, but many think Europa would be a good place to investigate the possibility of extraterrestrial life.

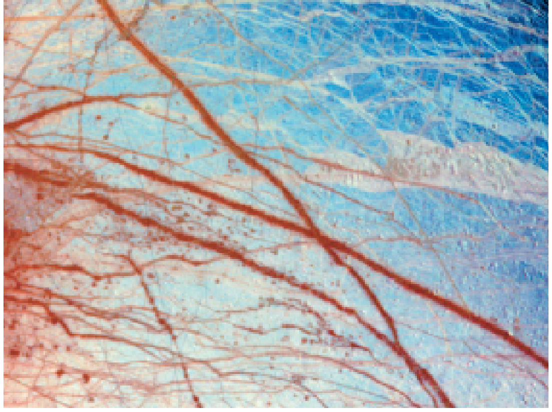


Figure 3 This false-color image of Europa shows immense cracks across its ice sheets.

Ganymede

Ganymede is the third Galilean moon from Jupiter. Ganymede is also the largest moon in the solar system, even larger than the planet Mercury. However, Ganymede has a relatively small mass because it is probably composed mostly of ice mixed with rock.

Images of Ganymede, such as **Figure 4,** show dark, crater-filled areas. Other light areas show marks that are thought to be long ridges and valleys. The *Galileo* spacecraft provided evidence to support the existence of a magnetic field around Ganymede. Ganymede is the only moon in the solar system that is known to have its own magnetic field. This magnetic field is completely surrounded by Jupiter's much more powerful magnetic field.

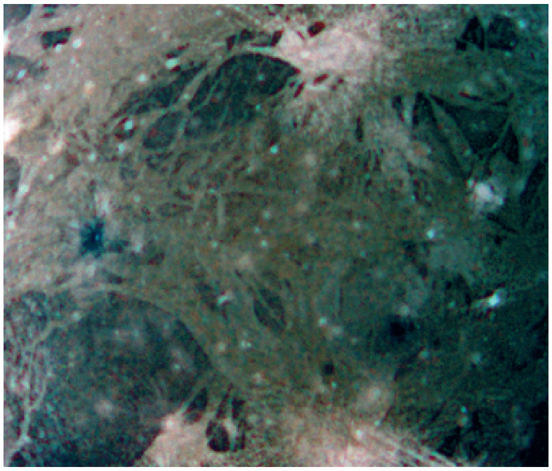


Figure 4 Much of Ganymede's surface is covered with ridges and valleys.

Callisto

Of the four Galilean moons, Callisto is the farthest from Jupiter. Callisto is similar to Ganymede in size, density, and composition. However, Callisto has a much rougher surface than Ganymede does. In fact, Callisto is one of the most densely cratered moons in our solar system.

Like craters on Earth's moon and other bodies in our solar system, craters on Callisto are the result of collisions that occurred early in the history of the solar system. **Figure 5** shows a giant impact basin that is 600 km across and a set of concentric rings that extend about 1,500 km outward in all directions from the crater.

Reading Check **Name one feature of each of the Galilean moons.**

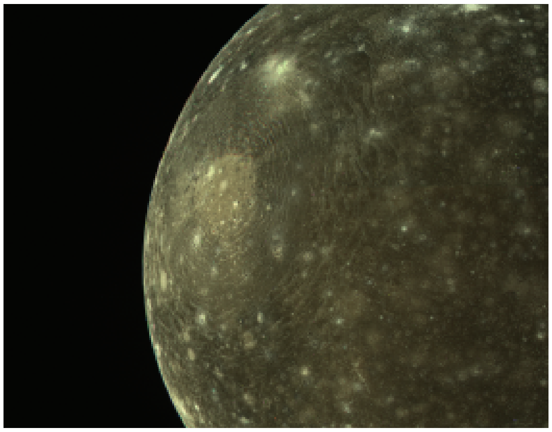


Figure 5 "Ripples" of ice and rock radiate out from this impact crater, called *Valhalla*, on Callisto.

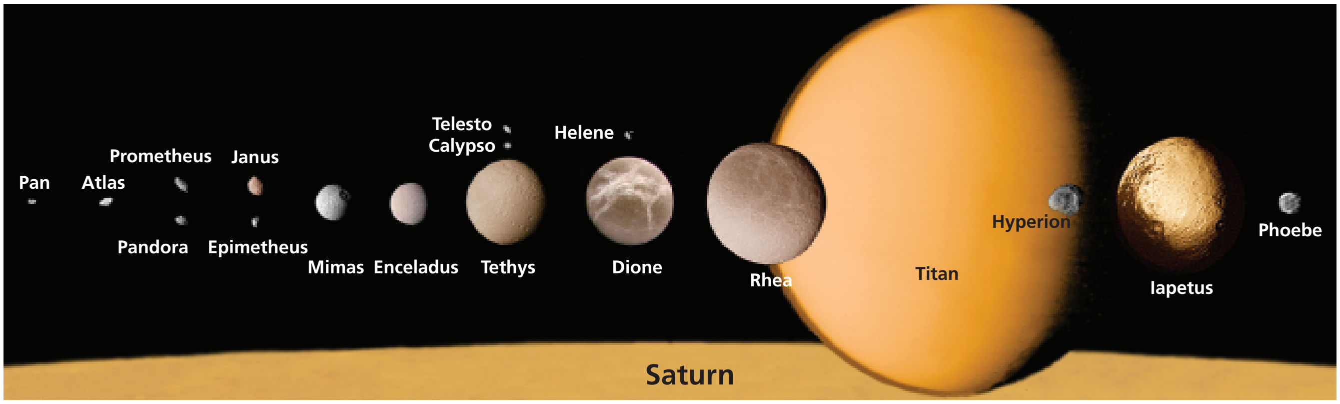


Figure 6 This composite image shows Saturn and many of Saturn's largest moons. The distances of the moons from Saturn and from each other are not to scale.

Moons of Saturn

Saturn has dozens of moons. Most of them are small, icy bodies that have many craters. However, five of Saturn's moons are fairly large. These five moons and many of Saturn's other moons are shown in **Figure 6.**

Titan

Saturn's largest moon, called Titan, has a diameter of more than 5,000 km. Only Jupiter's moon Ganymede is larger. Unlike any of the other moons in our solar system, Titan has a thick atmosphere that is composed mainly of nitrogen. Titan's atmosphere is so thick that hydrocarbon smog conceals most of the surface.

In 2005, the *Huygens* (HIE guhnz) probe, part of the Cassini mission, gathered data about Titan's atmosphere. The information it gathered is giving scientists clues about how Titan and its atmosphere formed. When the probe got below much of the atmosphere's haze, it sent back clear images of the surface, which showed signs of flowing liquid, probably methane. *Cassini* also sent back many images of Titan, an example of which is shown in **Figure 7.**

READING TOOLBOX

Two-Column Notes
Create two-column notes to review the main ideas for Sections 3 and 4. Put the main ideas in the left column, and add details and examples in your own words in the right column. Use as a model the two-column notes table that you started at the beginning of the chapter.

Saturn's Other Moons

Saturn's icy moons resemble Jupiter's icy Galilean moons. Enceladus has erupting geysers and so may have underground water near its surface. For that reason, it may be a better place to look for life than Europa. Saturn's other smaller moons have irregular shapes. Scientists think that many of the smallest moons, such as Janus, were captured by Saturn's gravity.

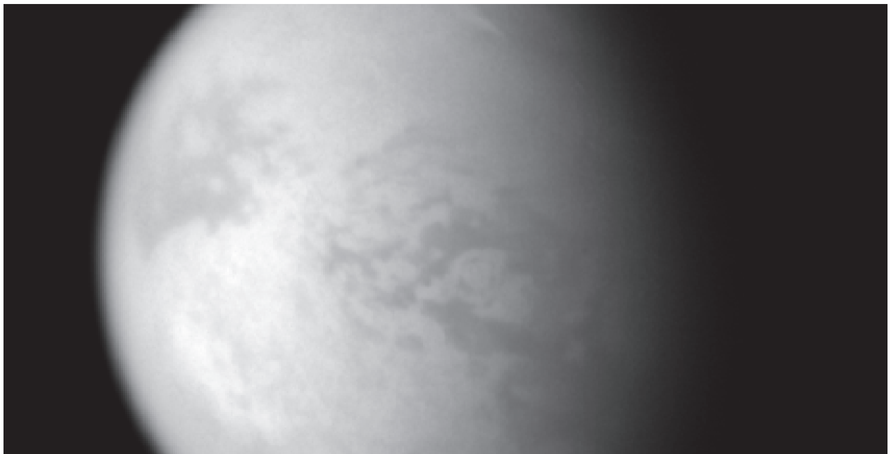


Figure 7 This image of Titan was taken by the Cassini mission in 2008. The image shows Titan in polarized infrared wavelengths by which clouds can be seen in its atmosphere.

Moons of Uranus and Neptune

Uranus's four largest moons, Oberon, Titania, Umbriel, and Ariel, were known by the mid-1800s. A fifth, Miranda, was discovered in 1948 and is shown in **Figure 8.** Other much smaller moons have been discovered recently by using spacecraft and orbiting observatories such as the *Hubble Space Telescope*. Astronomers know that Uranus has at least two dozen small moons.

Neptune has at least 13 moons. Triton, a large icy moon, is unusual because it revolves around Neptune in a backward, or *retrograde,* orbit. Some astronomers think that Triton has an unusual orbit because the moon was captured by the gravity of Neptune after forming elsewhere in the solar system and then coming too close to the planet. Triton's diameter is 2,705 km, and the moon has a thin atmosphere.

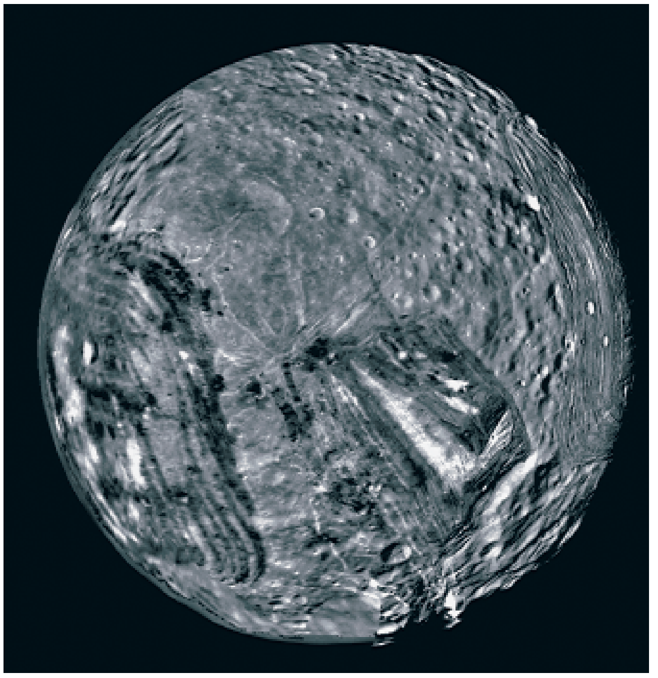


Figure 8 Uranus's moon called Miranda shows intriguing evidence of past geologic activity.

Pluto's Moons

Although Pluto is no longer officially considered a planet, it does have at least three moons. Pluto's largest moon, Charon (KER uhn), is almost half the size of Pluto. In fact, because Pluto and Charon are so similar in mass, they both orbit a common balance point, or *barycenter*, that is located between them. Charon orbits Pluto in 6.4 days, the same length of time as a day on Pluto. Because of these equal lengths, Charon stays in the same place in Pluto's sky. In the same way that one side of Earth's moon always faces Earth, one side of Pluto always faces Charon.

Pluto's other two moons, Hydra and Nix, are much smaller. These moons were discovered in 2005 by astronomers using the *Hubble Space Telescope*. These moons also orbit the barycenter between Pluto and Charon.

Reading Check **Identify two ways Charon is different from other moons.**

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Topic: Moons of Other Planets
Code: HQX0993

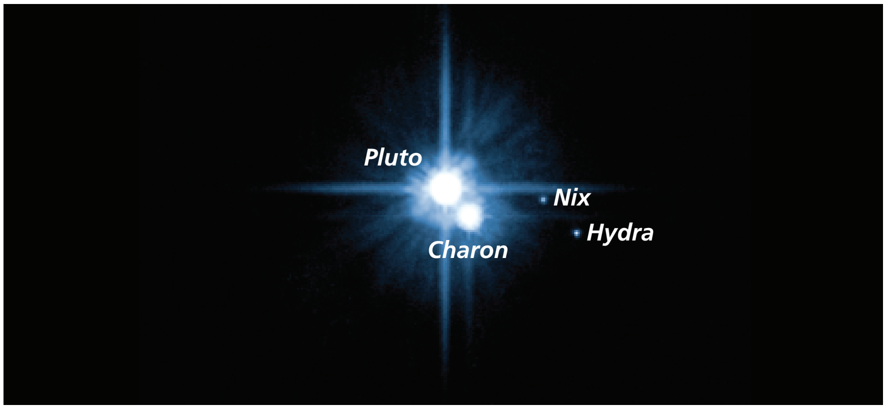

Figure 9 Pluto was discovered in 1930, Charon was discovered in 1978, and two smaller moons, Nix and Hydra, were discovered in 2005. (The spikes of light in the image are effects of the telescope.)

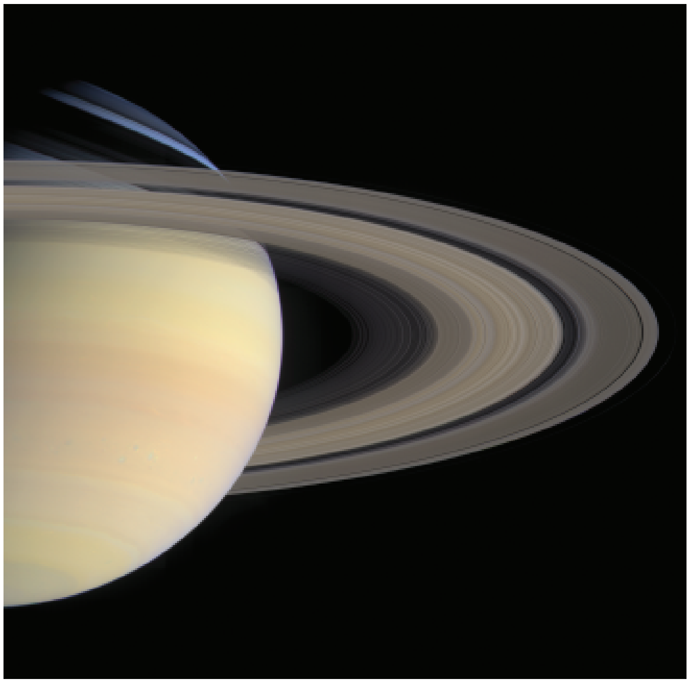

Figure 10 Saturn has the most extensive system of rings in the solar system. The angle at which its rings are visible changes as Saturn orbits the sun.

Rings of the Gas Giants

Saturn's spectacular set of rings, shown in **Figure 10,** was discovered more than 300 years ago. Each of the rings circling Saturn is divided into hundreds of small ringlets. The ringlets are composed of billions of pieces of rock and ice. These pieces range in size from particles the size of dust to chunks the size of a house. Each piece follows its own orbit around Saturn. The ring system of Saturn is very thin.

Originally, astronomers thought that the rings formed from material that was unable to clump together to form moons while Saturn was forming. However, evidence indicates that the rings are much younger than originally thought. Now, most scientists think that the rings are the remains of a large cometlike body that entered Saturn's system and was ripped apart by tidal forces. Particles from the rings continue to spiral into Saturn, but the rings are replenished by particles given off by Saturn's moons.

The other gas giants have rings as well. These rings are relatively narrow. Jupiter's were not discovered until the *Voyager 1* spacecraft flew by Jupiter in 1979. Jupiter has a single, thin ring made of microscopic particles that may have been given off by Io or one of Jupiter's other moons. The particles may also be debris from collisions of comets or meteorites with Jupiter's moons. Uranus also has a dozen thin rings. Neptune's relatively small number of rings are clumpy rather than thin and uniform.

Section 3 Review

Key Ideas

1. **Compare** the characteristics of Phobos and Deimos.
2. **List** the four moons of Jupiter that were discovered by Galileo, and identify one distinguishing characteristic of each.
3. **Describe** how volcanoes were discovered on Io.
4. **Explain** why Io remains volcanically active.
5. **Describe** how the smaller moons of Uranus were discovered.
6. **Explain** why Triton has an unusual orbit.
7. **Compare** the characteristics of Saturn's rings with the rings of the other outer planets.

Critical Thinking

8. **Analyzing Relationships** Explain why scientists think that Ganymede's interior includes ice.
9. **Inferring Relationships** Compare and contrast the way in which moons and ring systems form.
10. **Making Comparisons** Explain why Triton retains an atmosphere while Phobos does not.

Concept Mapping

11. Use the following terms to create a concept map: *moon, ring, Mars, Uranus, Jupiter, Saturn, Phobos, Deimos, Pluto, Galilean moon, natural satellite, Charon, Titania,* and *Titan.*

SECTION 4 Asteroids, Comets, and Meteoroids

Key Ideas	Key Terms	Why It Matters
❯ Describe the physical characteristics of asteroids and comets. ❯ Describe where the Kuiper Belt is located. ❯ Compare meteoroids, meteorites, and meteors. ❯ Explain the relationship between the Oort cloud and comets.	**asteroid** **comet** **Kuiper Belt** **Oort cloud** **meteoroid** **meteor**	Some asteroids are close enough to Earth that they could cause significant damage if one were to strike Earth. For this reason, some scientists keep track of known asteroids and their orbits.

In addition to the sun, the planets, and the planets' moons, our solar system includes millions of smaller bodies. Some of these small bodies are tiny bits of dust or ice that orbit the sun. Other bodies are as big as small moons. Astronomers theorize that these smaller bodies are leftover debris from the formation of the solar system.

Asteroids

The largest of the minor bodies in the solar system are called asteroids. **Asteroids** are fragments of rock that orbit the sun. Astronomers have discovered more than 300,000 asteroids. Millions of asteroids may exist in the solar system. The orbits of asteroids, like those of the planets, are ellipses. The largest known asteroid, Ceres, has a diameter of about 1,000 km. Because it is large enough that gravity has caused it to become round, Ceres is also considered to be a dwarf planet. Two other asteroids are shown in **Figure 1.**

asteroid a small, rocky object that orbits the sun; most asteroids are located in a band between the orbits of Mars and Jupiter

Most asteroids are located in a region between the orbits of Mars and Jupiter known as the *asteroid belt*. This main belt extends from about 299 million to about 598 million kilometers from the sun. However, not all asteroids are located in the main asteroid belt. The closest asteroids to the sun are inside the orbit of Mars, about 224 million kilometers from the sun. The *Trojan asteroids* are concentrated in groups just ahead of and just behind Jupiter as it orbits the sun. In fact, the Trojan asteroids almost share Jupiter's orbit. These asteroids are named for the Trojan and Greek warriors of the famous Trojan War of Greek mythology. Asteroids also exist beyond Jupiter's orbit.

Figure 1 This image of the asteroids Ida (left) and Dactyl (right) were taken by the spacecraft *Galileo* as it passed through the asteroid belt on its way to Jupiter. Ida is 56 km long, and Dactyl is 1.5 km across.

Academic Vocabulary

composition (KAHM puh ZISH uhn) the substances that make up an object

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Topic: Comets, Asteroids, and Meteoroids
Code: **HQX0317**

READING TOOLBOX

Word Origins

The asteroid Pallas is named after the Greek goddess of wisdom, war, and the arts, Pallas Athena. As you read Section 4, find the origins of the names of asteroids and comets. Add them to the table that you started at the beginning of the chapter.

Composition of Asteroids

The composition of asteroids is similar to that of the inner planets. Asteroids are classified according to their composition into three main categories. The most common of the three types of asteroids is made mostly of carbon materials, which give this type of asteroid a dark color. The second type of asteroid is made of mostly silicate minerals. These asteroids look like Earth rocks. The third, and rarest, type of asteroid is composed of mostly iron and nickel. These asteroids have a shiny, metallic appearance, especially on fresh surfaces.

Many astronomers think that asteroids in the asteroid belt are made of material that was not able to form a planet because of the strong gravitational force of Jupiter. Scientists estimate that the total mass of all asteroids is less than the mass of Earth's moon.

Near-Earth Asteroids

More than a thousand asteroids have orbits that sometimes bring them very close to Earth. These asteroids have wide, elliptical orbits that bring them near Earth's orbit. Thus they are called *near-Earth asteroids*. Near-Earth asteroids make up only a small percentage of the total number of asteroids in the solar system.

Interest in near-Earth asteroids has increased in recent years with the realization that these asteroids could inflict great damage on Earth if they were to strike the planet. Meteor Crater, in Arizona, which is shown in **Figure 2,** formed when a small asteroid that had a diameter of less than 50 m struck Earth about 49,000 years ago. Several recently established asteroid detection programs have begun to track all asteroids whose orbits may approach Earth. By identifying and monitoring these asteroids, scientists hope to predict and possibly avoid future collisions.

Reading Check **What are the three types of asteroids by composition?**

Figure 2 Barringer Meteorite Crater, also known simply as Meteor Crater, in Arizona, has a diameter of more than 1 km. Dozens of such craters have resulted from past impacts on Earth, but most craters have eroded or have been covered by sediment.

Figure 3 A comet, such as Comet Hale-Bopp consists of a nucleus, a coma, and two tails. The blue streak is the *ion tail,* and the white streak is the *dust tail.*

Comets

Every few years, an object that looks like a star that has a tail is visible in the evening sky. This object is a comet. **Comets** are small bodies of ice, rock, and cosmic dust that follow highly elliptical orbits around the sun. The most famous is Halley's Comet, which passes by Earth every 76 years. It last passed Earth in 1986 and will return in 2061. Every 5 to 10 years, another very bright comet will be visible from Earth. Comet Hale-Bopp, shown in **Figure 3,** was particularly spectacular as it passed Earth in 1997, as was comet McNaught in 2007.

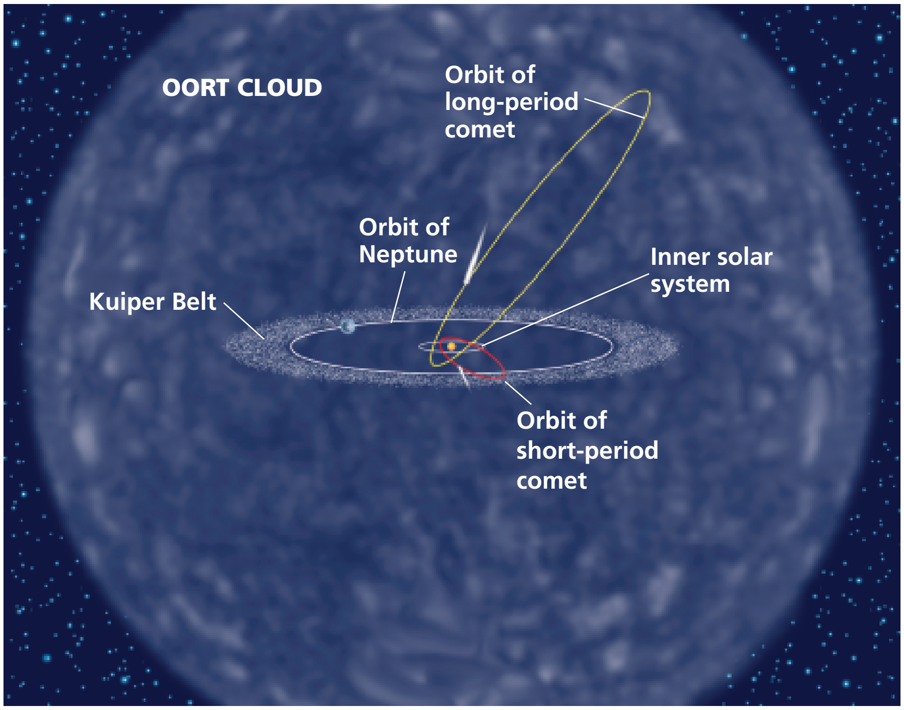
comet a small body of rock, ice, and cosmic dust that follows an elliptical orbit around the sun and that gives off gas and dust in the form of a tail as it passes close to the sun

Composition of Comets

A comet has several parts. The core, or nucleus, of a comet is made of rock, metals, and ice. Cores of comets are commonly between 1 km and 100 km in diameter. A spherical cloud of gas and dust, called the *coma,* surrounds the nucleus. The coma can extend as far as 1 million kilometers from the nucleus. A comet's bright appearance largely results from sunlight reflected by the comet's coma. The nucleus and the coma form the head of the comet. In 2004, the spacecraft *Stardust* flew by a comet named Wild 2. It returned samples from the comet's coma to Earth in 2006. In 2005, the spacecraft, *Deep Impact,* slammed a probe into the nucleus of comet Temple 1. The probe released a plume of dust, giving scientists a look at what a comet's nucleus is made of. The *Rosetta* spacecraft will go into orbit around a comet in 2014 and will drop a lander onto its surface.

The most spectacular parts of a comet are its tails. Tails form when sunlight causes the comet's ice to change to gas. The gas, or ion, tail of a comet streams from the comet's head. The solar wind—electrically charged particles expanding away from the sun—pushes the gas away from the comet's head. Thus, regardless of the direction the comet travels, its ion tail points away from the sun. The comet's second tail is made of dust and curves backward along the comet's orbit. Some comets have tails that are more than 80 million kilometers long.

Figure 4 Most comets come from the Oort cloud, a region in the outer solar system that is far beyond the orbit of Neptune.



Kuiper Belt a region of the solar system that starts just beyond the orbit of Neptune and that contains dwarf planets and other small bodies made mostly of ice

Oort cloud a spherical region that surrounds the solar system, that extends from the Kuiper Belt to almost halfway to the nearest star, and that contains billions of comets

The Kuiper Belt

Recent advances in technology have allowed scientists to observe thousands of small objects beyond the orbit of Neptune. Most of these objects, including some comets, are from a ring of icy bodies called the **Kuiper Belt** (KIE puhr BELT), which is located just beyond Neptune's orbit. The Kuiper Belt is also illustrated in **Figure 4.** The dwarf planets Pluto and Eris are located in the Kuiper Belt. Several other objects that are candidates for dwarf-planet status also reside in the Kuiper Belt.

The Oort Cloud

Astronomers think that most comets originate in the Oort cloud, which is illustrated in **Figure 4.** The **Oort cloud** is a spherical cloud of dust and ice that lies far beyond Neptune's orbit and that contains the nuclei of billions of comets. The total mass of the Oort cloud is estimated to be between 10 and 40 Earth masses.

The Oort cloud surrounds the solar system and may reach as far as halfway to the nearest star. Scientists think that the matter in the Oort cloud was left over from the formation of the solar system. Studying this distant matter helps scientists understand the early history of the solar system.

Bodies within the Oort cloud circle the sun so slowly that they take a few million years to complete one orbit. But the gravity of a star that passes near the solar system may cause a comet to fall into a more elliptical orbit around the sun. The orbits of comets that pass by Jupiter may also be changed by Jupiter's gravitational force. If a comet takes more than 200 years to complete one orbit of the sun, the comet is called a *long-period comet*.

Short-Period Comets

Comets called *short-period comets* take less than 200 years to complete one orbit around the sun. In recent years, astronomers have discovered that most short-period comets come from the Kuiper Belt. Some of the comets that originate in the Kuiper Belt have been forced outward into the Oort cloud by Jupiter's gravity. Many comets in the Kuiper Belt are the result of collisions between larger Kuiper-Belt objects there. Halley's comet, which has a period of 76 years, is a short-period comet.

Math Skills

Matter From Space
Astronomers estimate that about 1 million kg of matter from meteoroids falls to Earth each day. Based on this estimate, how many kilograms of matter from meteoroids would fall on Earth in three weeks?

Meteoroids

In addition to relatively large asteroids and comets, very small bits of rock or metal move throughout the solar system. These small, rocky bodies are called **meteoroids.** Most meteoroids have a diameter of less than 1 mm. Scientists think that most meteoroids are pieces of matter that become detached from passing comets. Large meteoroids—more than 1 cm in diameter—are probably the result of collisions between asteroids.

meteoroid a relatively small, rocky body that travels through space

meteor a bright streak of light that results when a meteoroid burns up in Earth's atmosphere

Meteors

Meteoroids that travel through space on an orbit that takes them directly into Earth's path may enter Earth's atmosphere. When a meteoroid enters Earth's atmosphere, friction between the object and the air molecules heats the meteoroid's surface. As a result of this friction and heat, most meteoroids burn up in the atmosphere. As a meteoroid burns up in Earth's atmosphere, the meteoroid produces a bright streak of light called a **meteor.** Meteors are commonly called *shooting stars*. Meteoroids sometimes also vaporize very quickly in a brilliant flash of light called a *fireball*. Observers on Earth may hear a loud noise as a fireball disintegrates.

When a large number of small meteoroids enter Earth's atmosphere in a short period of time, a *meteor shower* occurs. During the most spectacular of these showers, several meteors are visible every minute. A composite photo of a meteor shower is shown in **Figure 5.** Meteor showers occur at the same time each year. This happens because Earth intersects the orbits of comets that have left behind a trail of dust. As these particles burn up in Earth's atmosphere, they appear as meteors streaking across the sky.

Reading Check **What is the difference between a meteor and a meteoroid?**

Figure 5 The straight lines in this composite photo are meteors burning up as they move through Earth's atmosphere.

Figure 6 Types of Meteorites

Meteorites

Millions of meteoroids enter Earth's atmosphere each day. A few of these meteoroids do not burn up entirely in the atmosphere because they are relatively large. These meteoroids fall to Earth's surface. A meteoroid or any part of a meteoroid that is left when a meteoroid hits Earth is called a *meteorite*. Most meteorites are small and have a mass of less than 1 kg. However, large meteorites occasionally strike Earth's surface with the force of a large bomb. These impacts leave large impact craters.

Meteorites can be classified into three basic types: stony, iron, and stony-iron. These three types of meteorites are shown in **Figure 6.** *Stony meteorites* are similar in composition to rocks on Earth. Some stony meteorites contain carbon-bearing compounds that are similar to the carbon compounds in living organisms. Although most meteorites are stony, *iron meteorites* are easier to find. Iron meteorites are easier to find because they have a distinctive metallic appearance. This distinctive appearance makes iron meteorites easy to distinguish from common Earth rocks. The third type of meteorites, called *stony-iron meteorites,* contain iron and stone. Stony-iron meteorites are rare.

Astronomers think that almost all meteorites come from collisions between asteroids. The oldest meteoroids may be 100 million years older than Earth and its moon. Therefore, meteorites may provide information about how the early solar system formed.

Some rare meteorites originated on the moon or Mars. Computer simulations have shown that meteorites that hit the moon or Mars can eject rocks that then fall to Earth. Many of these rare meteorites have been found in Antarctica. Finding meteorites in Antarctica is relatively easy because they stand out against the background of snow and ice.

Section 4 Review

Key Ideas

1. **Identify** where the asteroid belt is located in the solar system.
2. **Describe** the physical characteristics of asteroids.
3. **List** the four main parts of a comet, and identify their physical characteristics.
4. **Compare** the ion and dust tails of a comet.
5. **Explain** the relationship between the Oort cloud and comets.
6. **Describe** the location of the Kuiper Belt.
7. **Distinguish** between a meteor, a meteoroid, and a meteorite.

Critical Thinking

8. **Analyzing Relationships** Explain why a comet's ion tail always points away from the sun.
9. **Making Comparisons** Explain how iron meteorites can be distinguished from common rocks of Earth's crust.
10. **Making Comparisons** You find a meteorite on the ground. What kind of meteorite did you most likely find? Describe two steps of its journey from space.

Concept Mapping

11. Use the following terms to create a concept map: *comet, asteroid, Kuiper Belt, Oort cloud, long-period comet, short-period comet,* and *meteoroid.*

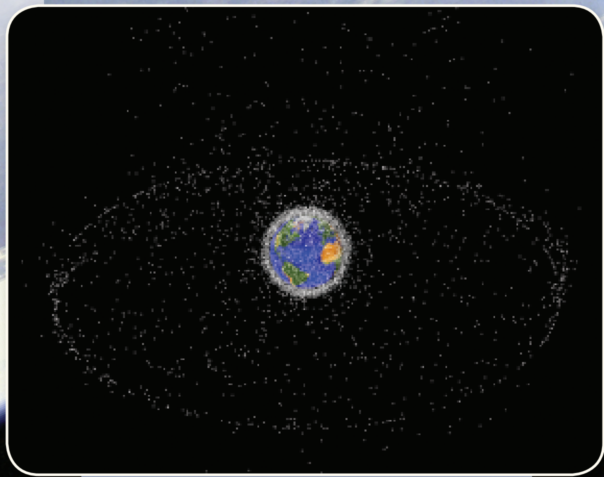
Why It Matters

SCIENCE & SOCIETY

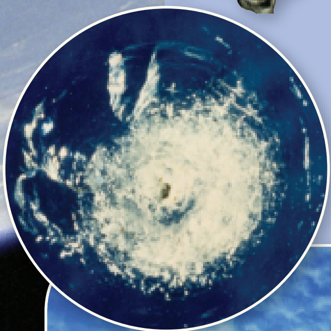
Dodging Space Debris

The glove that astronaut Edward White lost during the first U.S. spacewalk in 1965 was certainly the fastest-moving glove in history. It circled Earth repeatedly at a speed of 28,000 km/h before burning up in the atmosphere about a month later. The same fate awaits an average of 100 to 200 basketball-sized (or larger) objects each year, as well as innumerable objects 1 cm in size or smaller. NASA calls these objects orbital debris, but their more colorful name is space junk.

Lottie Williams, in Turley, Oklahoma, was grazed in the shoulder by a lightweight fragment. This is the only known case of a person being struck by space debris.



This graphic shows the estimated 100,000-plus pieces of space debris larger than 1 cm. Pieces less than 1 cm number many millions. Most do not survive reentry, so there is little danger to people or property.



This windshield damage was caused by a 0.2 mm fragment of space debris traveling 3 to 6 km/s—equivalent to the damage from a rifle bullet.

In 1997, this 32 kg pressure sphere and two other items from a Delta II rocket booster landed in Texas. A fourth booster item struck Lottie Williams.

YOUR TURN

UNDERSTANDING CONCEPTS

Even though most pieces of space debris are tiny, why are they an important concern?

CRITICAL THINKING

How can tiny pieces of debris cause such significant damage?

Skills Practice Lab

90 min

What You'll Do

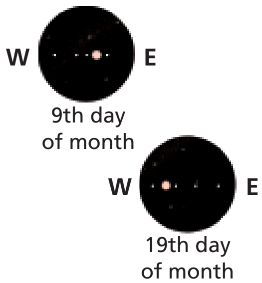
- **Calculate** the value of a constant, *K*.
- **Explain** how Kepler's law of periods explains orbits of moons of Jupiter.

What You'll Need

calculator
metric ruler

Galilean Moons of Jupiter

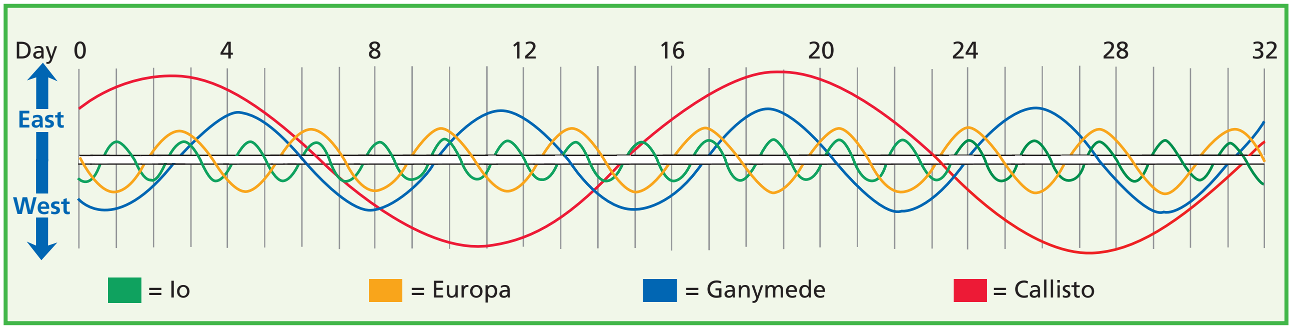
Kepler's third law of motion—the law of periods—explains the relationship between a planet's distance from the sun and the planet's period (the time required to make one revolution around the sun). According to the law of periods, the cube of the average distance of the planet from the sun is proportional to the square of the planet's period. Kepler's third law can be expressed mathematically as $K \times a^3 = p^2$, in which *a* is the average distance from the sun, *p* is the period, and *K* is a constant. Kepler's third law also may be applied to moons orbiting a planet, in which *a* is the average distance of a moon to the planet and *p* is the moon's period. In this activity, you will verify that the orbital motions of Jupiter's moons obey Kepler's third law.



Step 1 The central horizontal band on the chart below represents Jupiter. When a moon's path crosses in front of this band, the moon is in front of the planet. When a moon's path crosses behind this band, the moon is behind Jupiter.

Procedure

1. Two telescope eyepiece views at the left show how Jupiter and its four largest, or Galilean, moons appear through a telescope on Earth at midnight on the 9th and 19th day of a month. Compare these illustrations with the chart below, which shows the path of each moon as it orbits Jupiter during the same month.
   a. List the days when each of Jupiter's moons crosses in front of the planet.
   b. List the days when each of the moons is behind Jupiter.
2. Use the data in the table on the next page to test Kepler's third law. Calculate p^2 and a^3 for each of the planets. Record your results in a table of your own. Then, calculate *K* for each planet by using Kepler's third law, $K = p^2/a^3$. Record your results in a similar table.
3. Draw Jupiter and its moons as they would appear from Earth at midnight on the 2nd and 26th of the month.



4. Draw Jupiter's moons on the first day of the month that all four moons are on the same side of the planet. Identify the date.
5. Give a date when only two moons will be visible. Name the two visible moons.
6. Follow each moon's motion on the chart. Find the length of time, in Earth days, required for each moon to orbit Jupiter. To do this, measure the time between two points when the moon is in exactly the same position on the same side of Jupiter. Record your answers in a table with columns for moons, *p* (in Earth days), *a* (in mm), p^2, a^3, and *K*.
7. Measure the scale distance between the maximum outward swing of each moon and the center of Jupiter in millimeters. Record your answers in your table.
8. Square each period measurement, and record the answer in your table. Cube each distance measurement, and record the answer.
9. Use your results to test Kepler's third law. Because $K = p^2/a^3$, divide p^2 by a^3 for each moon to find *K*. Record your results in your table.

Kepler's Third Law

Planet	*p* (in Earth years)	*a* (in billions of km)	a^3	p^2	*K*
Mercury	0.24	0.058			
Venus	0.62	0.108			
Earth	1	0.150			
Mars	1.88	0.228			
Jupiter	11.86	0.778			
Saturn	29.46	1.427			
Uranus	83.8	2.871			
Neptune	163.7	4.497			

DO NOT WRITE IN THIS BOOK

Analysis

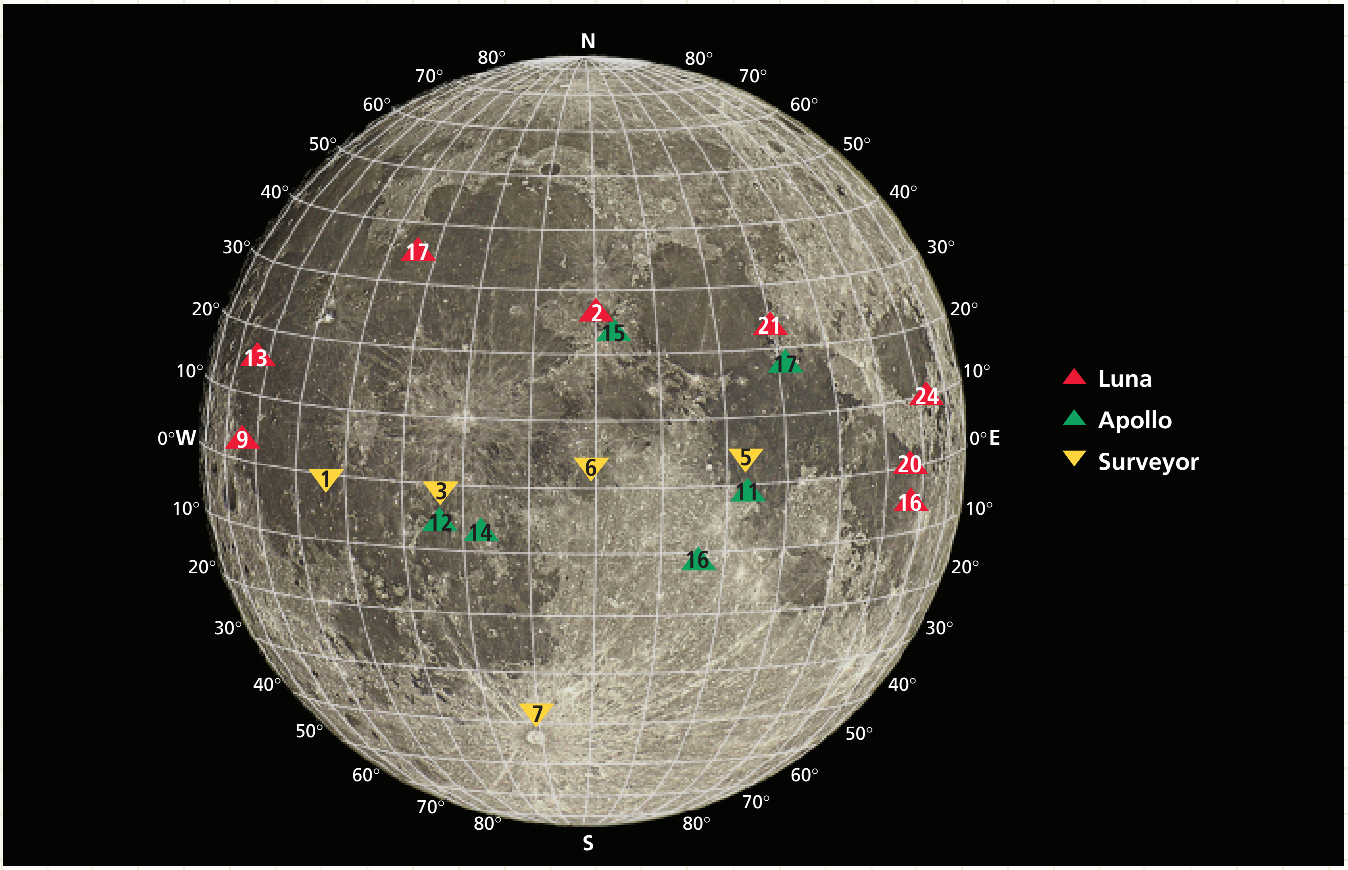
1. **Analyzing Events** Will you see all four of Jupiter's largest moons each time you look at Jupiter through a telescope or binoculars? Explain your answer.
2. **Making Inferences** If you look at Jupiter's moons through a telescope, they look like dots. If you had no charts, how could you identify each moon?
3. **Drawing Conclusions** After you solve for *K* for each moon, study your results. Is *K* a constant for the moons of Jupiter? Explain your answer.

Extension

Making Calculations Recalculate the values of *K* for the planets by using astronomical units instead of kilometers. How does this affect the amount of variation in the value of the constant?

MAPS *in Action*

Lunar Landing Sites



Map Skills Activity

This map shows the surface of the near side of the moon and the landing sites of both lunar missions that had crews and lunar missions that did not have crews. Most Surveyor missions took place before the Apollo missions. The Luna missions were launched by the former Soviet Union. Use the map to answer the questions below.

1. **Using a Key** How many Luna missions landed on the moon?
2. **Using a Key** How many Surveyor missions landed on the moon's southern hemisphere?
3. **Analyzing Data** How many Apollo missions landed close to Surveyor mission landing sites?
4. **Making Comparisons** At which areas of latitude are no landing sites located?
5. **Making Comparisons** In what 10° range of latitude are most landing sites located?
6. **Inferring Relationships** Based on the locations of most landing sites, what surface features do you think interested scientists?
7. **Identifying Trends** The missions to the moon used radio communications. Radio communications require a clear path between the transmitter and receiver. Taking these facts into consideration, how many landing sites would you expect to find on the far side of the moon? Explain your answer.

Chapter 28 Summary

THINK central
SUPER SUMMARY
Keyword: HQXMBSS

Section 1

Earth's Moon

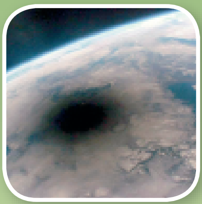
Key Ideas

- Lunar surface features include maria, craters, rilles, ridges, regolith, and rocks.
- The moon's crust averages about 80 km deep. Extending about 1,000 km below the crust is the rocky mantle, which may be surrounded by a partly solid and partly liquid iron core that is less than 700 km in radius.
- The moon is thought to be a chunk of Earth's early mantle ejected as a result of a giant impact with a Mars-sized body. As the early molten moon cooled, it developed its three layers. Craters and regolith formed from meteorite impacts.

Key Terms

satellite, p. 785
moon, p. 785
mare, p. 786
crater, p. 786

Section 2

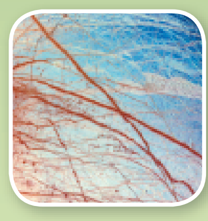


Movements of the Moon

- The shape of the moon's orbit around Earth is an ellipse.
- Eclipses occur when one planetary body passes through the shadow of another.
- The full moon phase shows a fully illuminated moon. Third quarter shows a half-moon (left side lit). New moon is not visible. First quarter shows a half-moon (right side lit).
- Tides result largely from the moon's gravitational pull on Earth.

apogee, p. 791
perigee, p. 791
eclipse, p. 793
solar eclipse, p. 793
lunar eclipse, p. 795
phase, p. 796

Section 3



Satellites of Other Planets

- Phobos and Deimos are irregularly shaped with many craters. They revolve around Mars quickly.
- The Voyager spacecraft discovered volcanoes on Io.
- The four Galilean moons of Jupiter are Io (known for its volcanoes), Europa (with an icy coating and possibly liquid water), Ganymede (the largest moon in the solar system), and Callisto (a very densely cratered moon).
- Saturn has many more rings than other planets do.

Galilean moon, p. 799

Section 4

Asteroids, Comets, and Meteoroids

- Asteroids are large, rocky bodies. Comets are smaller and are made of rock, ice, and dust.
- The Kuiper Belt is located beyond the orbit of Neptune.
- Meteoroids are small rocky bodies. The streak of light made when they burn up in the atmosphere is called a meteor. Any part that reaches the ground is called a meteorite.
- Most comets are thought to originate in the Oort cloud.

asteroid, p. 805
comet, p. 807
Kuiper Belt, p. 808
Oort cloud, p. 808
meteoroid, p. 809
meteor, p. 809

Chapter 28 Review

1. Describing Space Name two words that describe the motion of all minor bodies of the solar system, and explain how the meanings of these words differ.

READING TOOLBOX

USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *crater*
3. *mare*
4. *Galilean moon*

For each pair of terms, explain how the meanings of the terms differ.

5. *perigee* and *apogee*
6. *Oort cloud* and *Kuiper Belt*
7. *solar eclipse* and *lunar eclipse*
8. *comet* and *asteroid*
9. *meteoroid* and *meteorite*

UNDERSTANDING KEY IDEAS

10. Dark areas on the moon that are smooth and that reflect little light are called
    a. rilles.
    b. rays.
    c. maria.
    d. breccia.
11. What happened in the most recent stage in the development of the moon?
    a. The densest material sank to the core.
    b. The crust began to break.
    c. Earth's gravity captured the moon.
    d. The number of meteorites hitting the moon decreased.
12. During each orbit around Earth, the moon spins on its axis
    a. 1 time.
    b. about 29 times.
    c. about 27 times.
    d. 365 times.
13. In a lunar eclipse, the moon
    a. casts a shadow on Earth.
    b. is in Earth's shadow.
    c. is between Earth and the sun.
    d. blocks part of the sun from view.
14. When the size of the lighted part of the moon's near side is decreasing, the moon is
    a. full.
    b. waxing.
    c. annular.
    d. waning.
15. Compared with the other moons of Jupiter, the four Galilean moons are
    a. larger.
    b. farther from Jupiter.
    c. lighter.
    d. younger.
16. The main asteroid belt exists in a region between the orbits of
    a. Mercury and Venus.
    b. Earth and Mars.
    c. Venus and Earth.
    d. Mars and Jupiter.
17. Meteorites can provide information about
    a. the composition of the solar system before the planets formed.
    b. the size of Earth.
    c. the destiny of the solar system.
    d. the size of the universe.

SHORT ANSWER

18. Describe how maria formed on the moon.
19. Are craters on the moon caused by volcanism or by impacts with other bodies? Explain your answer.
20. Do total eclipses of the sun occur only at full moons? Explain your answer.
21. Are any moons in the solar system bigger than planets? Explain.
22. Which planets have rings?
23. Which two places in the solar system do comets come from?
24. What is the difference between natural and artificial satellites?

CRITICAL THINKING

25. Analyzing Relationships If Earth had two moons that traveled on the same orbit and were the same distance from Earth, but formed a 90° angle with Earth, how would Earth's tides be different?

26. Making Inferences How would the craters on the moon be different today if the moon had developed a dense atmosphere that moved as wind and that contained water?

27. Determining Cause and Effect If meteorites had stopped hitting the moon before the outer surface of the moon cooled, how would the moon's surface be different than it is today?

28. Evaluating Information Suppose that the moon spun twice on its axis during each orbit around Earth. How would the study of the moon from Earth be easier than it is currently?

29. Applying Ideas The surfaces of some asteroids reflect only small amounts of light. Other asteroids reflect up to 40% of the light that falls on them. Of what kind of materials would each type of asteroid probably be composed?

CONCEPT MAPPING

30. Use the following terms to create a concept map: *moon, Earth, apogee, perigee, new moon, full moon, waxing, waning, solar eclipse, lunar eclipse, umbra, penumbra,* and *phase.*

MATH SKILLS

Math Skills

31. Making Calculations There are 60 s in 1 min, 60 min in 1 h, 24 h in 1 day, and 365 1/4 days in a year. How many seconds are in a year?

32. Making Calculations The radius of Earth's moon is 1,738 km. The diameter of Neptune's moon Triton is 2,705 km. What percentage of Earth's moon's size is Triton?

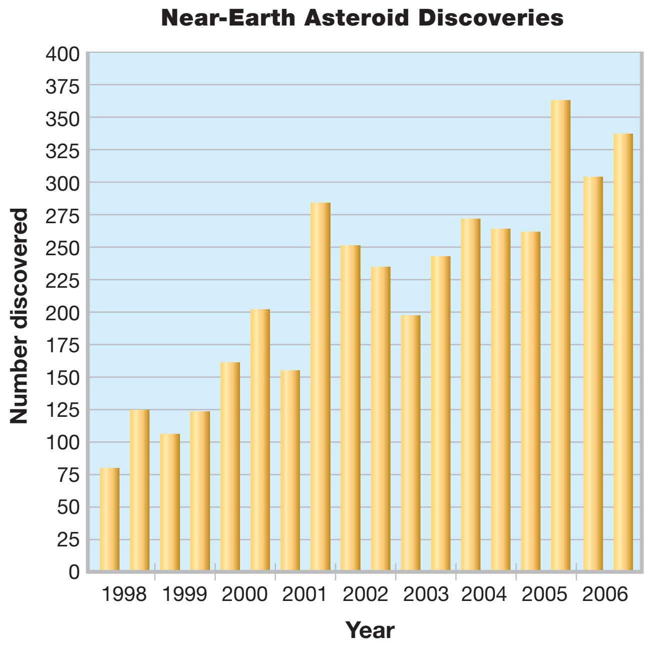
WRITING SKILLS

33. Creative Writing Imagine that you want to live on the moon. Describe how you would get your water and how you would acquire food and other supplies.

34. Communicating Ideas Summarize how the moon's gravity and the rotation of Earth cause tides.

INTERPRETING GRAPHICS

The graph below shows the number of near-Earth asteroids discovered each year. Use the graph below to answer the questions that follow.



35. Was the rate of discovery of near-Earth asteroids in 2006 higher or lower than the rate in 2005?

36. How many near-Earth asteroids were discovered in the half-year in which the most discoveries were made?

37. Which calendar year had the highest total number of near-Earth asteroid discoveries?

38. What is the total number of near-Earth asteroids discovered in the last three years shown on the graph?

Chapter 28 Standardized Test Prep

Understanding Concepts

Directions (1–4): For each question, write on a separate sheet of paper the letter of the correct answer.

1. Because of differences in surface gravity, how much does a person who weighs 360 newtons (360 N) on Earth weigh on the moon?
- **A.** 36 N
- **B.** 60 N
- **C.** 180 N
- **D.** 90 N

2. The point in the orbit of a satellite at which the satellite is farthest from Earth is the satellite's
- **F.** apogee.
- **G.** perigee.
- **H.** barycenter.
- **I.** phase.

3. Which of the following statements accurately describes each ring of Saturn?
- **A.** It is divided into smaller ringlets, all of which orbit Saturn together.
- **B.** It consists of a single ring composed of rock and ice pieces.
- **C.** It is divided into smaller ringlets, each of which has an individual orbit.
- **D.** It is part of a set of rings that are unlike those found anywhere else.

4. Which of the following statements describes why temperature variation on the moon is so large?
- **F.** The moon has no atmosphere to provide insulation.
- **G.** The atmosphere of the moon is made up of cold gases.
- **H.** Gases are dense and close to the surface.
- **I.** Dark, smooth rocks absorb the sun's heat.

Directions (5–7): For each question, write a short response.

5. Approximately how long does it take the moon to make one orbit around Earth?

6. What are the names of the four moons of Jupiter known as the Galilean moons?

7. When the moon is at its apogee, what part of its shadow cannot reach Earth during an eclipse?

Reading Skills

Directions (8–11): Read the passage below. Then, answer the questions.

Kuiper Belt Objects

To explain the source of short-period comets, or comets that have a relatively short orbit around the sun, the Dutch-American astronomer Gerard Kuiper proposed in 1949 that a belt of icy bodies must lie beyond the orbits of Neptune and Pluto. Kuiper argued that comets were icy planetesimals that formed from the condensation that happened during the formation of our galaxy.

Because the icy bodies are so far from any large planet's gravitational field (30 to 100 AU), they are able to remain on the fringe of the solar system. Some theorists speculate that the large moons Triton and Charon were once independent members of the Kuiper Belt before they were captured by Neptune and Pluto, respectively. These moons and short-period comets have similar physical and chemical properties. Scientists now believe that the Kuiper Belt may be home to thousands of objects that have diameters of more than 100 km.

8. According to the information in the passage, which of the following did Gerard Kuiper think were actually icy planetesimals?
- **A.** outer planets
- **B.** comets
- **C.** moons of every planet
- **D.** inner planets

9. What two bodies do some scientists believe were once independent Kuiper-Belt objects?
- **F.** Neptune and Charon
- **G.** Neptune and Pluto
- **H.** Triton and Neptune
- **I.** Triton and Charon

10. What did the moon Triton orbit before it was captured by the gravity of Neptune?
- **A.** the sun
- **B.** Pluto
- **C.** the solar system
- **D.** Charon

11. Why did it take until the middle of the 20th century for astronomers to discover the presence of the Kuiper Belt?

Interpreting Graphics

Directions (12–15): For each question below, record the correct answer on a separate sheet of paper.

The diagram below shows the waxing and waning of the moon. Use this diagram to answer questions 12 and 13.

Phases of the Moon in the Northern Hemisphere

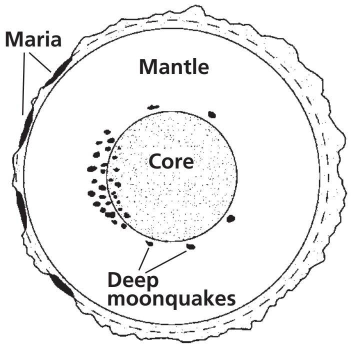
12. How would the appearance of the moon in the Southern Hemisphere be different from its appearance in the Northern Hemisphere?
- **F.** The phases of the moon would appear exactly the same.
- **G.** The Southern Hemisphere would see a full moon when the Northern Hemisphere sees a new moon.
- **H.** The moon would wax from left to right instead of from right to left.
- **I.** The Southern Hemisphere would see a waxing moon when the Northern Hemisphere sees a waning moon.

13. What part of the moon is facing Earth during the new moon in stage 1?
- **A.** the near side
- **B.** the far side
- **C.** the north pole
- **D.** the south pole

14. The word *wax* means "to grow larger," while *wane* means "to grow smaller." If the lighted portion of a waxing crescent is the same size as that of a waning crescent, why do you think these terms are used?

The diagram below shows data about the interior structure of the moon. Use this diagram to answer question 15.

Structure of the Moon



15. Where is the crust of the moon the thickest?
- **F.** at the poles
- **G.** at the equator
- **H.** on the near side
- **I.** on the far side

Test Tip

Test questions are not necessarily arranged in order of difficulty. If you are unable to answer a question, mark it and move on to other questions.