

Chapter 27

Planets of the Solar System

Chapter Outline

1 Formation of the Solar System

The Nebular Hypothesis
Formation of the Planets
Formation of Solid Earth
Formation of Earth's Atmosphere
Formation of Earth's Oceans

2 Models of the Solar System

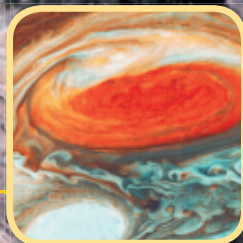
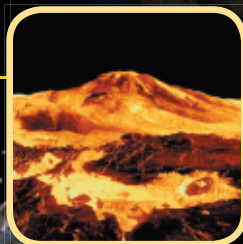
Early Models
Kepler's Laws
Newton's Explanation of Kepler's Laws

3 The Inner Planets

Mercury
Venus
Earth
Mars

4 The Outer Planets

Gas Giants
Jupiter
Saturn
Uranus
Neptune
Objects Beyond Neptune
Exoplanets



Why It Matters

Understanding the formation and the characteristics of our solar system and its planets can help scientists plan missions to study planets and solar systems around other stars in the universe.

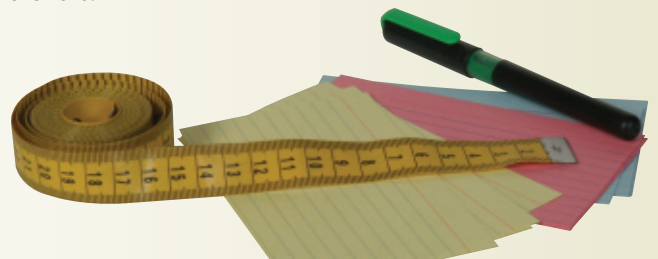
Inquiry Lab Planetary Distances



Turn to Appendix E and find the table entitled “Solar System Data.” Use the data from the “semimajor axis” row of planetary distances to devise an appropriate scale to model the distances between planets. Then find an indoor or outdoor space that will accommodate the farthest distance. Mark some **index cards** with the name of each planet, use a **measuring tape** to measure the distances according to your scale, and place each index card at its correct location.

Question to Get You Started

How would the distance of a planet from the sun affect the time it takes for the planet to complete one orbit?



Word Origins

Names of the Planets The ancient Romans named the five planets that they could see in the night sky after gods from their mythology: Mercury, Venus, Mars, Jupiter, and Saturn. When Uranus and Neptune were discovered, they were also named for Roman gods.

Your Turn Each planet was named for the god in mythology that has something in common with the planet. As you learn about the planets, complete the list of connections between the planets and the Roman gods for which they are named.

Planet	Characteristic of planet	Characteristic of Roman god
Mercury	fastest-moving planet	speedy messenger of the gods
Jupiter	largest planet	ruler of the Roman gods

Mnemonics

Order of the Planets A mnemonic is a sentence or phrase that you can create to help you remember information. For example, the order of the planets from the sun outward is Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. You can use a mnemonic to help you remember this order.

My **V**ery **E**nergetic **M**other
Just **S**erved **U**s **N**achos.

Notice that the first letter of each word is the same as the first letter of the corresponding planet in the order.

Your Turn Practice saying this mnemonic to help you learn and remember the order of the planets. Make up a new mnemonic that you could use to remember the order of the planets.

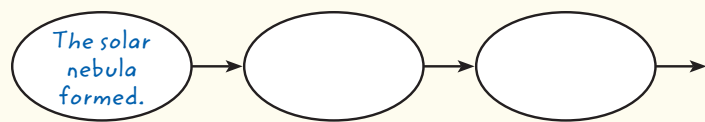
Graphic Organizers

Chain-of-Events Chart Use a chain-of-events chart when you need to remember the steps of a process.

Your Turn As you read Section 1, create a chain-of-events chart that outlines the formation of the solar system. An example has been started at the right.

1 Write the first step of the process in the first frame.

- 2** Write the next step of the process in the second frame, and use an arrow to show the order of the process.
- 3** Continue adding frames and arrows until the process for the formation of the solar system is complete.



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

SECTION
1

Formation of the Solar System

Key Ideas

- Explain the nebular hypothesis of the origin of the solar system.
- Describe how the planets formed.
- Describe the formation of the land, the atmosphere, and the oceans of Earth.

Key Terms

solar system
planet
solar nebula
planetesimal

Why It Matters

Studying the solar system and its various planets can help us understand our own planet and the changes it has been and is going through.

The **solar system** consists of the sun, the planets, the dwarf planets, and all of the other bodies that revolve around the sun. **Planets** are the primary bodies that orbit the sun. Scientists have long debated the origins of the solar system. In the 1600s and 1700s, many scientists thought that the sun formed first and threw off the materials that later formed the planets. But in 1796, the French mathematician Pierre-Simon, marquis de Laplace, advanced a hypothesis that is now known as the *nebular hypothesis*.

The Nebular Hypothesis

Laplace's hypothesis states that the sun and the planets condensed at about the same time out of a rotating cloud of gas and dust called a *nebula*. Modern scientific calculations support Laplace's hypothesis and help explain how the sun and the planets formed from an original nebula of gas and dust.

Matter is spread throughout the universe. Some of this matter gathers into clouds of dust and gas, such as the one shown in **Figure 1**. Almost 5 billion years ago, the amount of gravity near one of these clouds increased as a result of a nearby supernova or other forces. The rotating cloud of dust and gas from which the sun and planets formed is called the **solar nebula**. Energy from collisions and pressure from gravity caused the center of the solar nebula to become hotter and denser. When the temperature at the center became high enough—about 10,000,000°C—hydrogen fusion began. A star, which is called the sun, formed. The sun is composed of about 99% of all the matter that was contained in the solar nebula.

solar system the sun and all of the planets and other bodies that travel around it

planet a celestial body that orbits the sun, is round because of its own gravity, and has cleared the neighborhood around its orbital path

solar nebula a rotating cloud of gas and dust from which the sun and planets formed; *also* any nebula from which stars and exoplanets may form

Figure 1 The Orion nebula is about 1,500 light-years from Earth. Scientists study the nebula to learn about the processes that give birth to stars.



planetesimal a small body from which a planet originated in the early stages of development of the solar system

Academic Vocabulary

formation (fohr MAY shuhn) the act of giving structure or shape to something

SCILINKS

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Topic: Origins of the Solar System

Code: HQX1087

Formation of the Planets

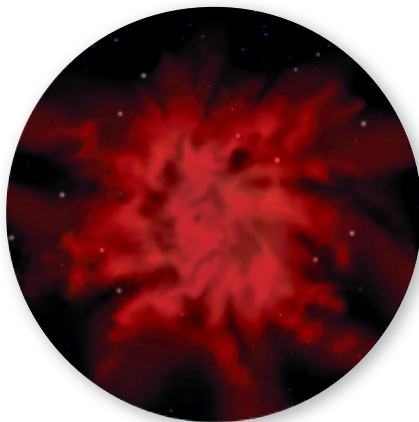
While the sun was forming in the center of the solar nebula, planets were forming in the outer regions, as shown in **Figure 2**. Small bodies from which a planet originated in the early stages of formation of the solar system are called **planetesimals**. Some planetesimals joined together through collisions and through the force of gravity to form larger bodies called *protoplanets*. The protoplanets' gravity attracted other planetesimals in the solar nebula. These planetesimals collided with the protoplanets and added their masses to the protoplanets.

Eventually, the protoplanets became very large and formed the planets and moons. *Moons* are the smaller bodies that orbit the planets. Planets and moons are smaller and denser than the protoplanets. Some protoplanets were massive enough to become round but not massive enough to clear away other objects near their orbits. These became the dwarf planets.

Formation of the Inner Planets

The features of a newly formed planet depended on the distance between the protoplanet and the developing sun. The four protoplanets that became Mercury, Venus, Earth, and Mars were close to the sun. They contained large percentages of heavy elements, such as iron and nickel. These planets lost their less dense gases because, at the temperature of the gases, gravity was not strong enough to hold the gases. Other lighter elements may have been blown or boiled away by radiation from the sun. As the denser material sank to the centers of the planets, layers formed. The less dense material was on the outer part of the planet, and the denser material was at the center. Today, the inner planets have solid surfaces that are similar to Earth's surface. The inner planets are smaller, rockier, and denser than the outer planets.

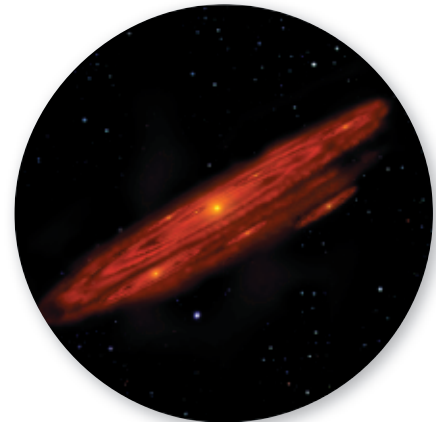
Figure 2 The Nebular Model of the Formation of the Solar System



The young solar nebula begins to collapse because of gravity.



As the solar nebula rotates, it flattens and becomes warmer near its center.



Planetesimals begin to form within the swirling disk.

Formation of the Outer Planets

Four other protoplanets became Jupiter, Saturn, Uranus, and Neptune. As a group, these outer planets are very different from the small, rocky inner planets. These outer planets formed in the colder regions of the solar nebula. They were far from the sun and therefore were cold. Thus, they did not lose their lighter elements, such as helium and hydrogen, or their ices, such as water ice, methane ice, and ammonia ice.

At first, thick layers of ice surrounded small cores of heavy elements. However, because of the intense heat and pressure in the planets' interiors, the ices melted to form layers of liquids and gases. Today, these planets are referred to as *gas giants* because they are composed mostly of gases, have low density, and are huge planets. Jupiter, for example, has a density of only 24% of Earth's density but a diameter that is 11 times Earth's diameter. Uranus and Neptune are different from Jupiter and Saturn, and are sometimes called *ice giants*.

Pluto—The First Dwarf Planet

From its discovery in 1930, Pluto was known as the ninth planet. However, it is quite unlike the other outer planets, which are gas giants or ice giants. In fact, Pluto is smaller than Earth's moon, and it can be best described as an ice ball that is made of frozen gases and rock. Its orbit is very tilted. Because of its characteristics, many astronomers disagreed with Pluto's classification as a planet.

In 2006, astronomers from around the world revised the definition of *planet*. The new definition includes the first eight familiar planets, but it excludes Pluto. Pluto is part of a new category of solar system bodies called *dwarf planets*.

Reading Check How is Pluto different from the outer planets? (See Appendix G for answers to Reading Checks.)

Quick Lab

5 min

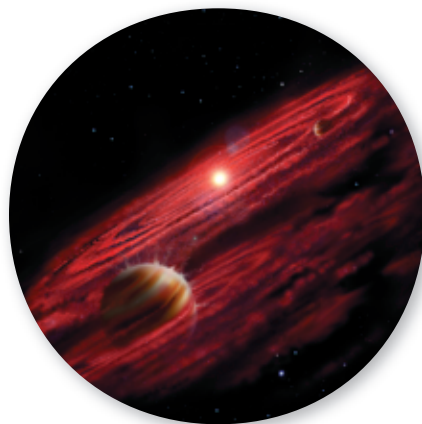
Water Planetesimals

Procedure

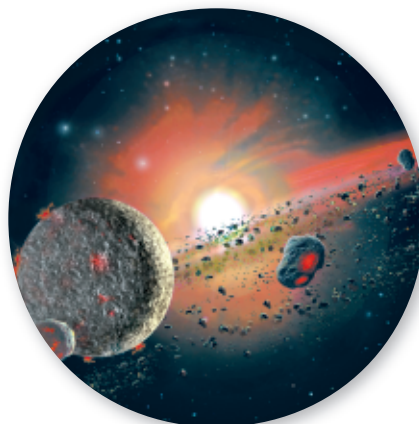
- 1 Use a **medicine dropper** to place two drops of **water** about 3 cm apart on a **piece of wax paper**.
- 2 Lift one edge of the wax paper so that one drop of water moves toward the other drop until the drops collide.
- 3 Add a third drop of water to the wax paper. Then, repeat step 2.

Analysis

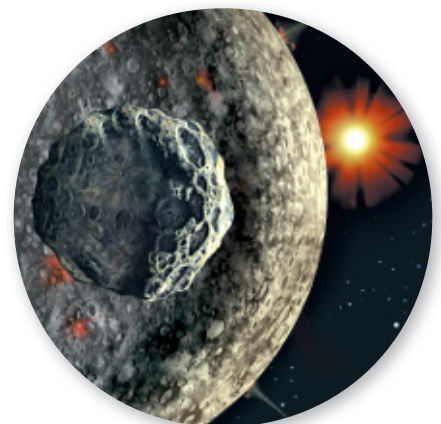
1. What happened when the water droplets collided?
2. How does this activity model the formation of protoplanets?



As planetesimals grow, their gravitational pull increases. The largest planetesimals begin to collect more of the gas and dust of the nebula.



Small planetesimals collide with larger ones, and the planets begin to grow.



The excess dust and gas is gradually removed from the solar nebula, which leaves planets around the sun and thus creates a new solar system.

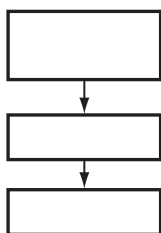
Formation of Solid Earth

When Earth first formed, it was very hot. Three sources of energy contributed to the high temperature on the new planet. First, much of the energy was produced when the planetesimals that formed the planet collided with each other. Second, the increasing weight of Earth's outer layers compressed the inner layers, which generated more energy. Third, radioactive materials that emit high-energy particles were very abundant when Earth formed. When surrounding rocks absorbed the particles, the energy of the particles' motion led to higher temperatures.

READING TOOLBOX

Chain-of-Events Chart

Make a chain-of-events chart. Then, fill in the chart with details about each step of the formation of Earth.



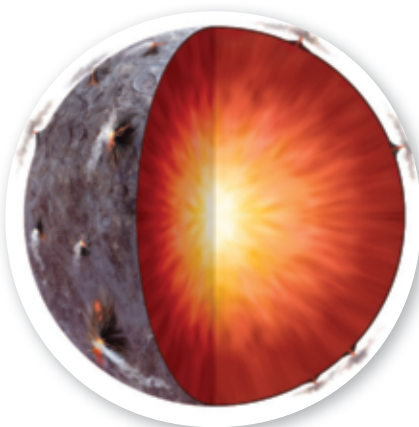
Early Solid Earth

Young Earth was hot enough to melt iron, the most common of the existing heavy elements. As Earth developed, denser materials, such as molten iron, sank to its center, and less dense materials were forced to the outer layers. This process is called *differentiation*. Differentiation caused Earth to form three distinct layers, as shown in **Figure 3**. At the center is a dense *core* that is composed mostly of iron and nickel. Around the core is the very thick layer of iron- and magnesium-rich rock called the *mantle*. The outermost layer of Earth is a thin *crust* of less dense, silica-rich rock. Today, processes that shape Earth, such as plate tectonics, are driven by heat transfer and differences in density.

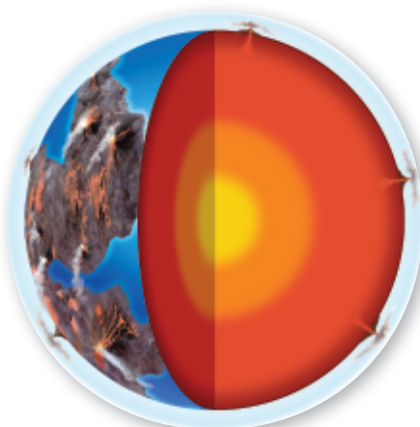
Present Solid Earth

Eventually, Earth's surface cooled enough for solid rock to form. The solid rock at Earth's surface formed from less dense elements that were pushed toward the surface during differentiation. Earth's surface continued to change as a result of the heat in Earth's interior as well as through impacts and through interactions with the newly forming atmosphere.

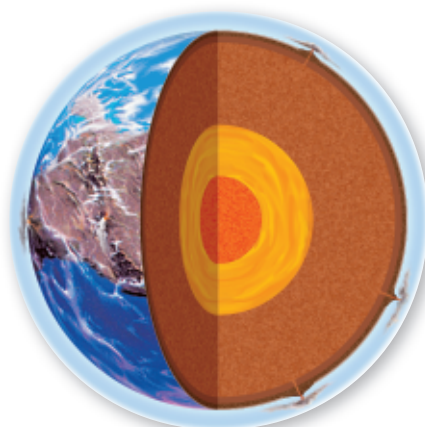
Figure 3 Differentiation of Earth



During its early history, Earth cooled to form three distinct layers.



An atmosphere began to form from the water vapor and carbon dioxide released by volcanic eruptions.



Organisms produced oxygen from photosynthesis to create an oxygenated atmosphere.

Formation of Earth's Atmosphere

Like solid Earth, the atmosphere formed because of differentiation. During the original differentiation of Earth, less dense gas molecules, such as hydrogen and helium, rose to the surface. Thus, the original atmosphere of Earth consisted primarily of hydrogen and helium.

Earth's Early Atmosphere

The high concentrations of hydrogen and helium did not stay with Earth's atmosphere. Earth's gravity would have been too weak to hold these gases unless they were very cold. The sun heated the gases enough so that they escaped Earth's gravity. These gases were probably blown away by the solar wind, which might have been stronger at that time than it is today. Also, Earth's magnetic field, which protects the atmosphere from the solar wind, might not have been fully developed.

Outgassing

As Earth's surface continued to form, volcanic eruptions were much more frequent than they are today. The volcanic eruptions released large amounts of gases, mainly water vapor, carbon dioxide, nitrogen, methane, sulfur dioxide, and ammonia, as shown in **Figure 4**. This process, known as *outgassing*, formed a new atmosphere.

The gases released during outgassing interacted with radiation from the sun. The solar radiation caused the ammonia and some of the water vapor in the atmosphere to break down. Most of the hydrogen that was released during this breakdown escaped into space. Some of the remaining oxygen formed *ozone*, a molecule that contains three oxygen atoms. The ozone collected in a high atmospheric layer around Earth and shielded Earth's surface from the harmful ultraviolet radiation of the sun.

Earth's Present Atmosphere

Organisms that could survive in Earth's early atmosphere developed. Some of these organisms, such as cyanobacteria and early green plants, used carbon dioxide during photosynthesis. Oxygen, a byproduct of photosynthesis, was released. So, the amount of oxygen in the atmosphere slowly increased. About 2 billion years ago, the percentage of oxygen in the atmosphere increased rapidly. Since that time, the chemical composition of the atmosphere has been similar to the present composition of the atmosphere, as shown in **Figure 5**.

Reading Check How did green plants contribute to Earth's present-day atmosphere?

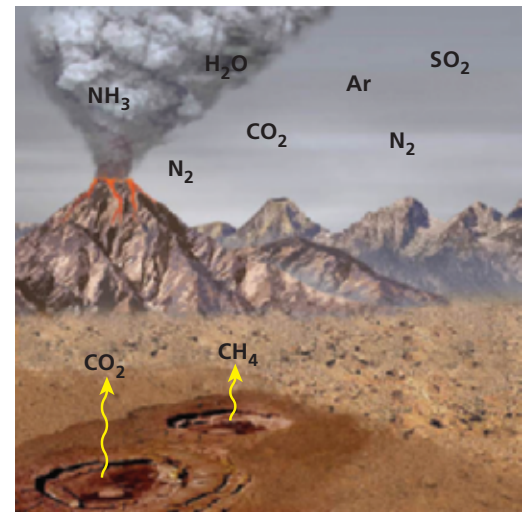


Figure 4 Earth's early atmosphere formed as volcanic eruptions released nitrogen, N₂; water vapor, H₂O; ammonia, NH₃; methane, CH₄; argon, Ar; sulfur dioxide, SO₂; and carbon dioxide, CO₂.

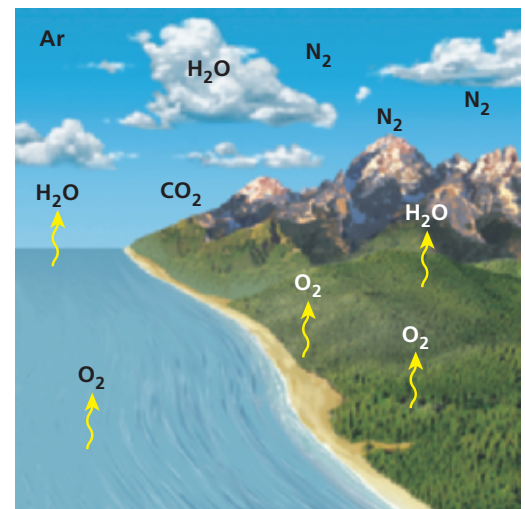


Figure 5 As Earth's surface changed, the gases in the atmosphere changed. Today, the atmosphere is 78% nitrogen, N₂; 21% oxygen, O₂; and 1% other gases.



Figure 6 Salt from the ocean can be harvested from salt flats, such as this one in Habantota, Sri Lanka.

Formation of Earth's Oceans

Some scientists think that part of Earth's water may have come from space. Early on, icy bodies, such as comets, collided with Earth. Water from these bodies then became part of Earth's atmosphere. As Earth cooled, water vapor condensed to form rain. This liquid water collected on the surface to form the first oceans.

The first ocean was probably made of fresh water. Over millions of years, rainwater fell to Earth and ran over the land, through rivers, and into the ocean. The rainwater dissolved some of the rocks on land and carried those dissolved solids into the oceans. As more dissolved solids were carried to the oceans, the concentration of certain chemicals in the oceans increased. As the water cycled back into the atmosphere through evaporation, some of these chemicals combined to form salts. Over millions of years, water has cycled between the oceans and the atmosphere. Through this process, the oceans have become increasingly salty. Where shallow ocean water has evaporated completely, the salt precipitates and is left behind. This salt may be harvested for human use, as shown in **Figure 6**.

The Ocean's Effects on the Atmosphere

The oceans affect global temperatures in a variety of ways. One way the oceans affect temperature is by dissolving carbon dioxide from the atmosphere. Scientists think that early oceans also affected Earth's early climate by dissolving carbon dioxide. Carbon dioxide in the atmosphere keeps energy from escaping into space and thus helps to heat the atmosphere. Over Earth's long history, the concentration of carbon dioxide has increased and decreased for various periods of time. Thus, at different times in its history, Earth likely has experienced climates that are warmer and cooler than the climates we experience today. 🌿

Section 1 Review

Key Ideas

- 1. Describe** the nebular hypothesis.
- 2. Explain** how planetesimals differ from protoplanets.
- 3. Describe** how planets developed.
- 4. Explain** why the outer planets are more gaseous than the inner planets.
- 5. List** three reasons that Earth was hot when it formed.
- 6. Summarize** the process by which the land, atmosphere, and oceans of Earth formed.

Critical Thinking

- 7. Identifying Relationships** How does the amount of gas in an outer planet differ from the amount of gas in an inner planet? Explain your answer.
- 8. Analyzing Ideas** Explain why Earth is capable of supporting life.

Concept Mapping

- 9.** Use the following terms to make a concept map: *solar system*, *solar nebula*, *protoplanet*, *planetesimal*, *planet*, and *gas giant*.

Models of the Solar System

Key Ideas

- Compare the models of the universe developed by Ptolemy and Copernicus.
- Summarize Kepler's three laws of planetary motion.
- Describe how Newton explained Kepler's laws of motion.

Key Terms

eccentricity
orbital period
inertia

Why It Matters

We can send people to the moon and rovers to Mars thanks to models of the solar system.

The first astronomers who studied the sky thought that the stars, planets, and sun revolved around Earth. This idea led to the first model of the solar system. However, the model changed as scientists learned more about how the solar system works.

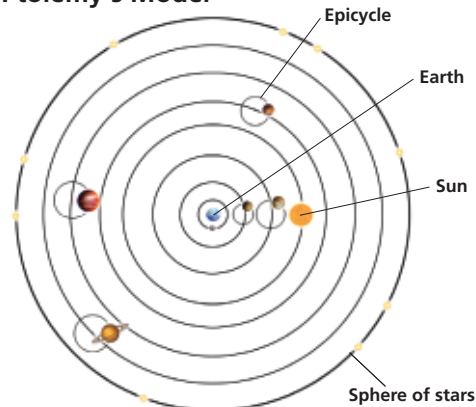
Early Models

More than 2,000 years ago, the Greek philosopher Aristotle suggested an Earth-centered, or *geocentric*, model of the solar system. In this model, the sun, the stars, and the planets revolved around Earth. However, this model did not explain why planets sometimes appeared to move backward in the sky relative to the stars—a pattern called *retrograde motion*.

By 150 CE, the Greek astronomer Claudius Ptolemy (TAHL uh mee) proposed changes to this model. Ptolemy thought that planets moved in small circles, called *epicycles*, as they revolved in larger circles around Earth. These epicycles seemed to explain why planets sometimes appeared to move backward.

In 1543 CE, a Polish astronomer named Nicolaus Copernicus proposed a sun-centered, or *heliocentric*, model of the solar system. In this model, the planets revolved around the sun in the same direction but at different speeds and distances from the sun. Fast-moving planets passed slow-moving planets. Therefore, planets that were slower than Earth appeared to move backward. **Figure 1** compares Ptolemy's and Copernicus's models. Later, the Italian scientist Galileo Galilei observed four moons traveling around the planet Jupiter. This observation indicated that objects can, and do, revolve around objects other than Earth.

Ptolemy's Model



Copernicus's Model

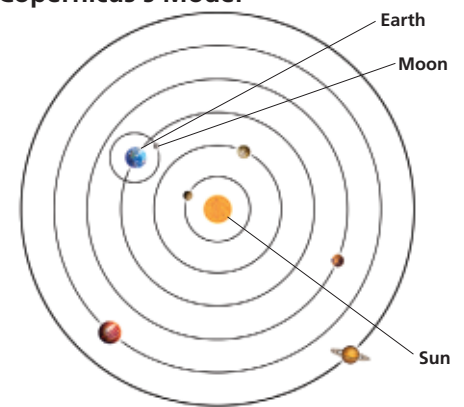


Figure 1 Early Solar System Models Ptolemy's solar system model (left) is Earth-centered and has the planets moving in epicycles around Earth. Copernicus's solar model (right) is heliocentric and has the planets moving at different speeds around the sun.

READING TOOLBOX

Mnemonic

Create a mnemonic to help you remember the three laws that Kepler developed to explain planetary motion.

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Topic: Early Astronomers

Code: HQX0441

eccentricity the degree of elongation of an elliptical orbit (symbol, e)

Kepler's Laws

Twenty years before Galileo used a telescope, the Danish astronomer Tycho Brahe made detailed observations of the positions of the planets. After Tycho's death, one of his assistants, Johannes Kepler, worked with Tycho's observations. His studies led Kepler to develop three laws that explained planetary motion.

Law of Ellipses

Kepler's first law, the *law of ellipses*, states that each planet orbits the sun in a path called an ellipse, not in a circle. An *ellipse* is a closed curve whose shape is determined by two points, or *foci*, within the ellipse. In planetary orbits, one focus is located within the sun. No object is located at the other focus. The combined length of two lines, one from each focus to any one point on the ellipse, would always be the same as the length of two other lines, one from each focus, to any other point on the same ellipse.

Elliptical orbits can vary in shape. Some orbits are elongated ellipses. Other orbit shapes are almost perfect circles. The shape of an orbit can be described by a numerical quantity called *eccentricity*. **Eccentricity** is the degree of elongation of an elliptical orbit (symbol, e). Eccentricity is determined by dividing the distance between the foci of the ellipse by the length of the major axis. Therefore, the eccentricity of a circular orbit is $e = 0$. The eccentricity of a type of extremely elongated orbit known as a parabolic orbit is $e = 1$.

 **Reading Check** Define and describe an ellipse.

Quick Lab Ellipses



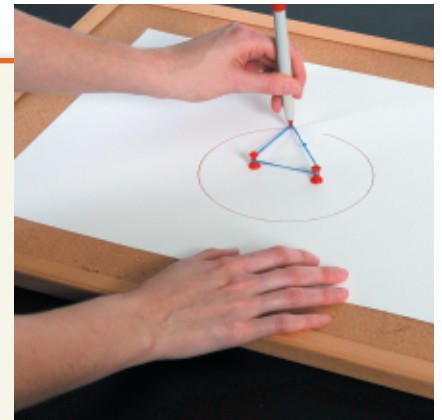
 15 min

Procedure

- 1 Cover a **cork board** with a **piece of paper**. Put **two push pins** into the cork board, 5 cm apart.
- 2 Tie together the ends of a **string** that is 25 cm long. Loop the string around the pins.
- 3 Hold the string taut with a **pencil**, and move the pencil to outline an ellipse.
- 4 Replace the paper with another **piece of paper**. Place the pins 10 cm apart. Outline another ellipse by using the string.
- 5 Use another **piece of paper**. Loop the string around one pin, and outline another ellipse.

Analysis

1. Which ellipse has an eccentricity closest to 0? Which has an eccentricity closest to 1? Describe the shape of your ellipse in terms of eccentricity.
2. Describe the ellipse as you increased the distance between the foci. Describe what would happen to the ellipse if you increased the length of the string without changing the distance between the foci.



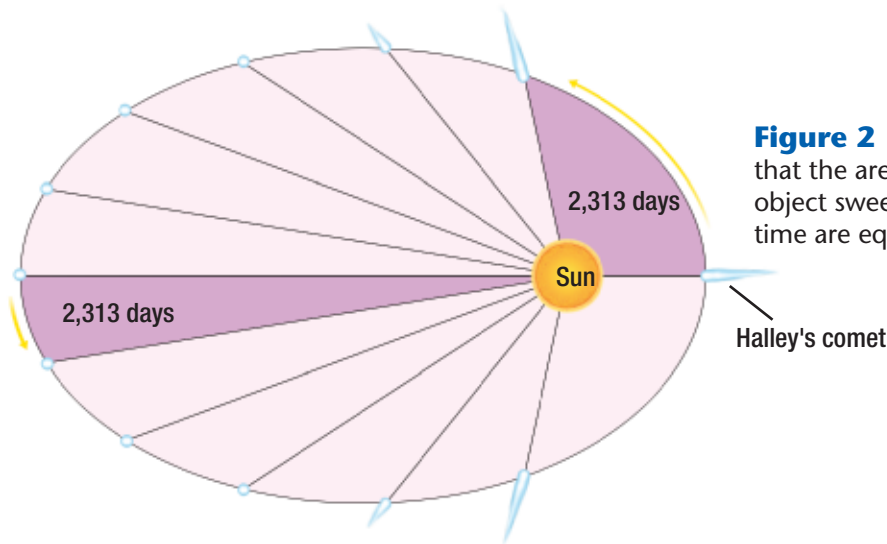


Figure 2 Kepler's second law states that the areas through which an object sweeps in a given period of time are equal.

THINK
central
INTERACT ONLINE
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Law of Equal Areas

Kepler's second law, the *law of equal areas*, describes the speed at which objects travel at different points in their orbits. Kepler discovered that Mars moves fastest in its elliptical orbit when it is closest to the sun. He calculated that a line from the center of the sun to the center of an object sweeps through equal areas in equal periods of time. This principle is illustrated in **Figure 2**.

Imagine a line that connects the center of the sun to the center of an object in orbit around the sun. When the object is near the sun, the imaginary line is short. The object moves relatively rapidly, and the line sweeps through a short, wide, pie-shaped sector. When the object is far from the sun, the line is long. However, the object moves relatively slowly when it is far from the sun, and the imaginary line sweeps through a long, thin, pie-shaped sector in the same period. Kepler's second law states that equal areas are covered in equal amounts of time as an object orbits the sun.

Law of Periods

Kepler's third law, the *law of periods*, describes the relationship between the average distance of a planet from the sun and the orbital period of the planet. The **orbital period** is the time required for a body to complete a single orbit. According to Kepler's third law, the cube of the average distance (a) of a planet from the sun is always proportional to the square of the period (p). The mathematical formula that describes this relationship is $K \times a^3 = p^2$, where K is a constant. When distance is measured in astronomical units (AU) and the period is measured in Earth years, $K = 1$ and $a^3 = p^2$.

Scientists can find out how far away the planets are from the sun by using this law, because they can measure the orbital periods by observing the planets. Jupiter's orbital period is 11.9 Earth years. The square of 11.9 is 142. The cubed number that is equal to 142 is 5.2, so Jupiter is 5.2 AU from the sun.

Math Skills

Law of Periods Suppose that scientists discover an asteroid that is 2.0 AU from the sun. If 1 AU = 150 million km, how long would the asteroid's orbital period be in Earth years?

orbital period the time required for a body to complete a single orbit



Figure 3 Comet Hyakutake, passing only 0.1 AU from Earth, is kept in orbit by the sun's gravitational pull.

inertia the tendency of an object to resist a change in motion unless an outside force acts on the object

Academic Vocabulary

exist (eg ZIST) to occur or be present

Newton's Explanation of Kepler's Laws

Isaac Newton asked why the planets move in the ways that Kepler observed. The explanation that Newton gave described the motion of objects on Earth and the motion of planets in space. He hypothesized that a moving body will remain in motion and resist a change in speed or direction until an outside force acts on it. This concept is called **inertia**. For example, a ball rolling on a smooth surface will continue to move unless a force causes it to stop or change direction.

Newton's Model of Orbits

Because a planet does not follow a straight path, an outside force must cause the orbit to curve. Newton gave this force the name *gravity*, and he realized that this attractive force exists between any two objects in the universe. The gravitational pull of the sun keeps objects, such as the comet shown in **Figure 3**, in orbit around the sun. While gravity pulls an object toward the sun, inertia keeps the object moving forward in a straight line. The sum of these two motions forms the ellipse of a stable orbit.

The farther from the sun a planet is, the weaker the sun's gravitational pull on the planet is. So, the outer planets are not pulled toward the sun as strongly as the inner ones are. As a result, the orbits of the outer planets are larger and are curved more gently, and the outer planets have longer periods of revolution than the inner planets do.

Section 2 Review

Key Ideas

- 1. Compare** Ptolemy's and Copernicus's models of the universe.
- 2. Identify** the role that Galileo played in developing the heliocentric theory.
- 3. Describe** the shape of planetary orbits.
- 4. Explain** the law of equal areas.
- 5. Summarize** Kepler's third law of planetary orbits.
- 6. Describe** how Newton explained Kepler's laws by combining the effects of two forces.

Critical Thinking

- 7. Applying Ideas** A comet's orbit is a highly elongated ellipse. So, why does a comet spend so little time in the inner solar system?
- 8. Making Comparisons** How did Kepler's explanation of the orbits of planets differ from Newton's explanation?

Concept Mapping

- 9.** Use the following terms to create a concept map: *retrograde motion*, *geocentric*, *heliocentric*, *ellipse*, *foci*, *gravity*, and *inertia*.

The Inner Planets

Key Ideas

- Identify the basic characteristics of the inner planets.
- Compare the characteristics of the inner planets.
- Summarize the features that allow Earth to sustain life.

Key Terms

terrestrial planet

Why It Matters

Studying other terrestrial planets helps scientists plan for human travel to, and colonization of, Mars.

The planets closest to the sun are called the *inner planets*. These planets are Mercury, Venus, Earth, and Mars. The inner planets are also called **terrestrial planets**, because they are similar to Earth. These planets consist mostly of solid rock and have metallic cores. The number of moons per planet varies from zero to two. The surfaces of inner planets have bowl-shaped depressions, called *impact craters*, that were caused by collisions of the planets with other objects in space.

Mercury

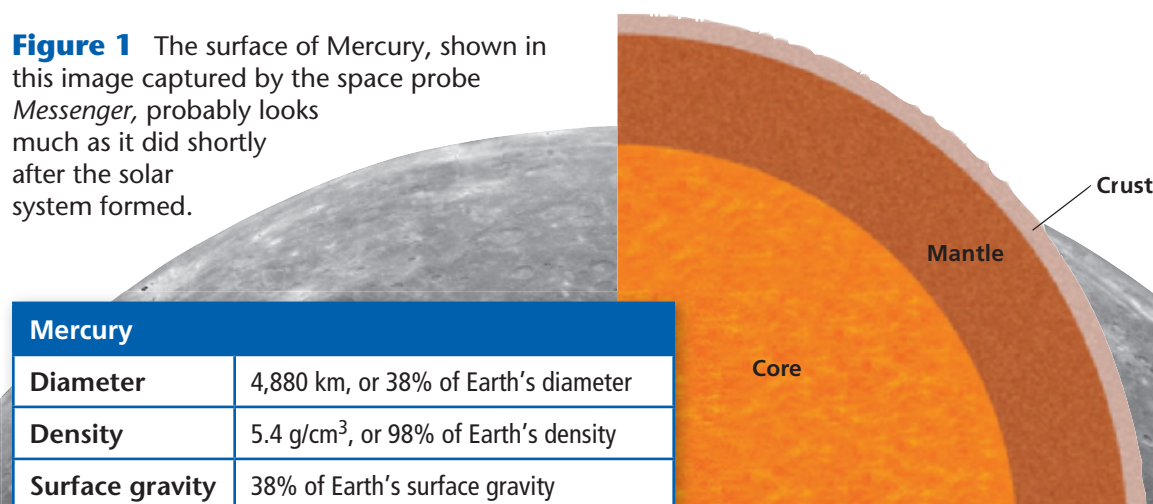
Mercury, the planet closest to the sun, circles the sun every 88 days. The ancient Romans named the planet after the messenger of the gods, who moved quickly. Mercury rotates on its axis once every 59 days.

Images of Mercury reveal a surface that is heavily cratered, as shown in **Figure 1**. The images also show a line of cliffs hundreds of kilometers long. These cliffs may be wrinkles that developed in the crust when the molten core cooled and shrank.

The absence of a significant atmosphere and the planet's slow rotation contribute to the large daily temperature range on Mercury. During the day, the temperature may reach as high as 427°C. At night, the temperature may plunge to -173°C.

terrestrial planet one of the highly dense planets nearest to the sun; Mercury, Venus, Mars, and Earth

Figure 1 The surface of Mercury, shown in this image captured by the space probe *Messenger*, probably looks much as it did shortly after the solar system formed.



Mercury

Diameter	4,880 km, or 38% of Earth's diameter
Density	5.4 g/cm ³ , or 98% of Earth's density
Surface gravity	38% of Earth's surface gravity

Venus

Venus is the second planet from the sun and has an orbital period of 225 days. However, Venus rotates very slowly, only once every 243 days. In some ways, Venus is Earth's twin. The two planets are of almost the same size, mass, and density. However, Venus and Earth differ greatly in other ways.

Venus's Atmosphere

✿ The biggest difference between Earth and Venus is Venus's atmosphere. Venus's atmospheric pressure is about 90 times the pressure on Earth. The high concentration of carbon dioxide in Venus's atmosphere and Venus's relative closeness to the sun have the strongest influences on surface temperatures. Venus's atmosphere is about 96% carbon dioxide.

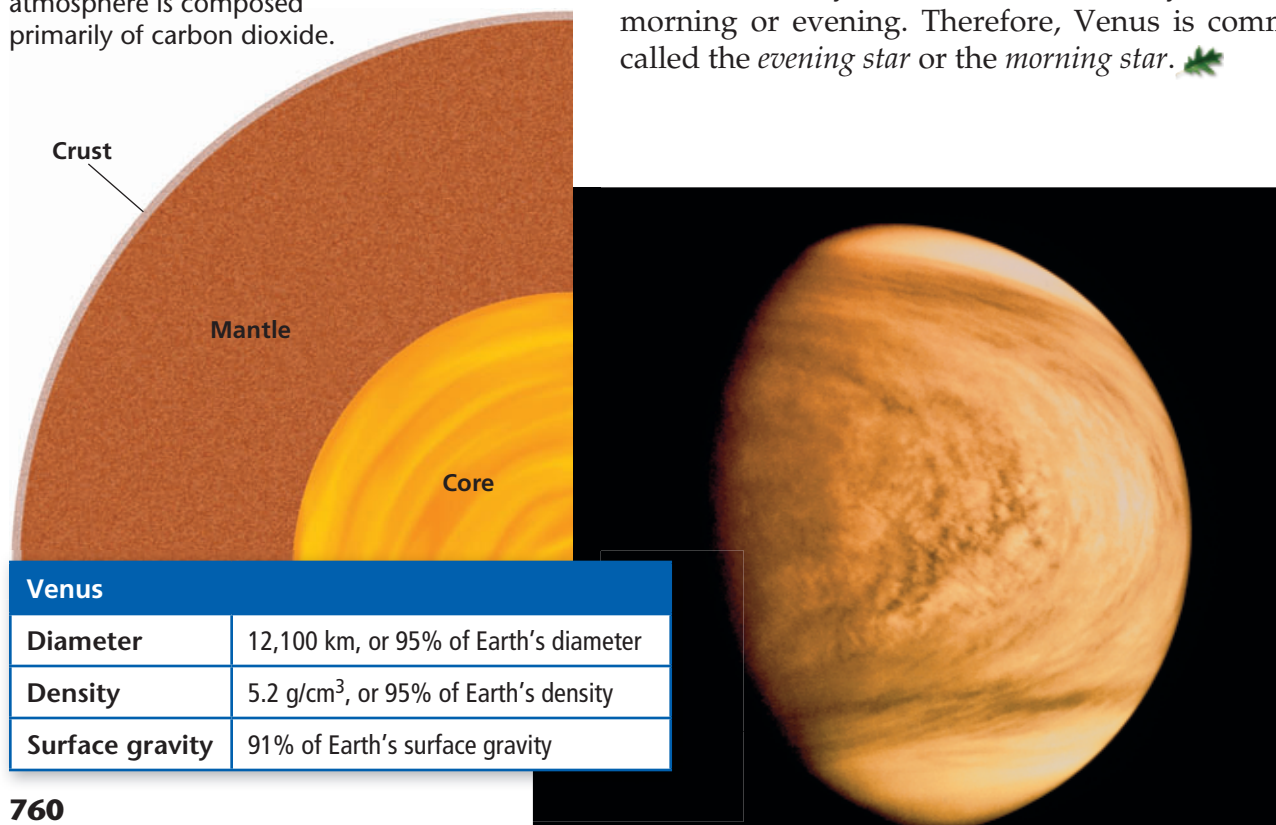
Solar energy that penetrates the atmosphere heats the planet's surface. The high concentration of carbon dioxide in the atmosphere blocks most of the infrared radiation from escaping. This type of heating is called a *greenhouse effect*. On Earth, the greenhouse effect warms Earth enough to allow organisms to live on the planet. But the greenhouse effect on Venus makes the average surface temperature 464°C! This phenomenon is commonly referred to as a *runaway greenhouse effect* and makes Venus's surface temperature the highest known in the solar system.

Venus also has sulfur dioxide droplets in its upper atmosphere. These droplets form a cloud layer that reflects sunlight. The cloud layer reflects the sunlight so strongly that, from Earth, Venus appears to be the brightest object in the night sky, aside from Earth's moon and the sun. Because Venus appears near the sun, Venus is usually visible from Earth only in the early morning or evening. Therefore, Venus is commonly called the *evening star* or the *morning star*. ✿

Academic Vocabulary

phenomenon (fuh NAHM uh NUHN)
any fact or event that can be sensed or described scientifically (plural, *phenomena*)

Figure 2 Venus's surface is composed of basalt and granite rocks. However, Venus's dense atmosphere is composed primarily of carbon dioxide.



Venus

Diameter	12,100 km, or 95% of Earth's diameter
Density	5.2 g/cm ³ , or 95% of Earth's density
Surface gravity	91% of Earth's surface gravity

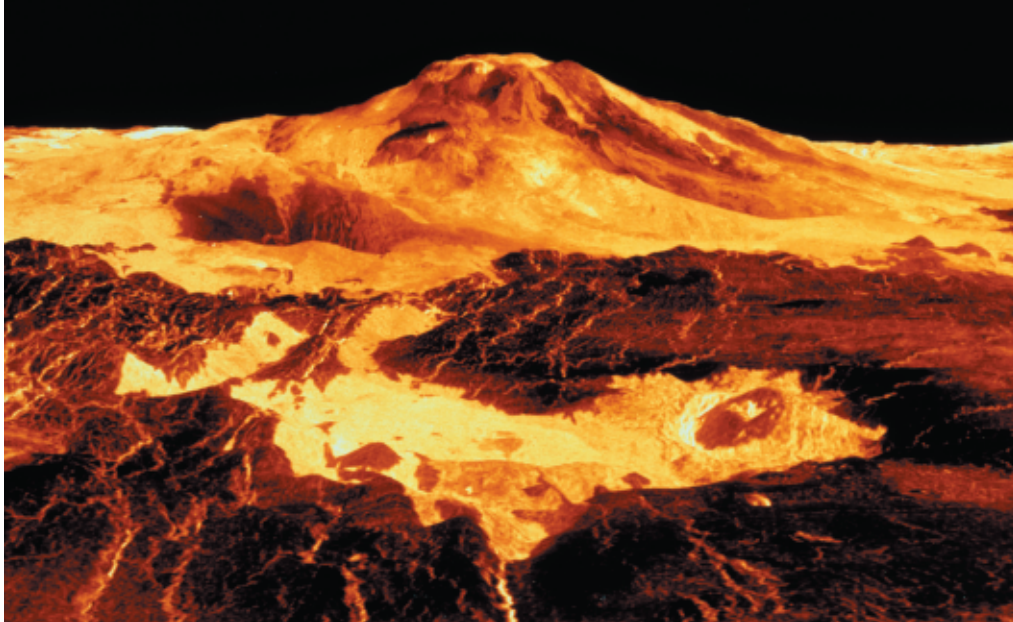


Figure 3 The scale of this computer-generated image of the Maat Mons volcano on Venus has been stretched vertically to make the topography look more dramatic. The image has also been color enhanced.

Missions to Venus

In the 1970s, the Soviet Union sent six probes to explore the surface of Venus. The probes survived in the atmosphere long enough to transmit surface images of a rocky landscape. The images showed a smooth plain and some rocks. Other instruments carried by the probes indicated that the surface of Venus is composed of basalt and granite. These two types of rock are also common on Earth.

The United States's *Magellan* satellite orbited Venus for four years in the 1990s before the satellite was steered into the planet to collect atmospheric data. *Magellan* also bounced radio waves off Venus to produce radar images of Venus's surface. The European Space Agency's *Venus Express* orbited Venus between April 2006 and May 2009.

Surface Features of Venus

From the radar mapping produced by *Magellan*, scientists discovered landforms such as mountains, volcanoes, lava plains, and sand dunes. Volcanoes and lava plains are the most common features on Venus. At an elevation of 8 km, the volcano Maat Mons, which is shown in **Figure 3**, is Venus's highest volcano.

The surface of Venus is also somewhat cratered. All the craters are about the same age, and they are surprisingly young. This evidence and the abundance of volcanic features on Venus's surface have led some scientists to speculate that Venus undergoes a periodic resurfacing as a result of massive volcanic activity. Energy inside the planet heats the interior over time, which causes the volcanoes to erupt and cover the planet's surface with lava. However, scientists think that another 100 million years may pass before volcanic activity again covers Venus's surface with lava. Venus's surface is very different from Earth's surface, which is constantly changing because of the motion of tectonic plates.

 **Reading Check** How is Venus different from Earth?

Math Skills

Distance from the Sun

Earth is about 150 million kilometers from the sun. Venus is 108.2 million kilometers from the sun. How much closer to the sun is Venus than Earth? Express your answer as a percentage.

Earth

✿ The third planet from the sun is Earth. The orbital period of Earth is 365¼ days, and Earth completes one rotation on its axis every day. Earth has one large moon.

Earth has had an extremely active geologic history. Geologic records indicate that over the last 250 million years, Earth’s continents separated from a single landmass and drifted to their present positions. Weathering and erosion have changed and continue to change the surface of Earth.

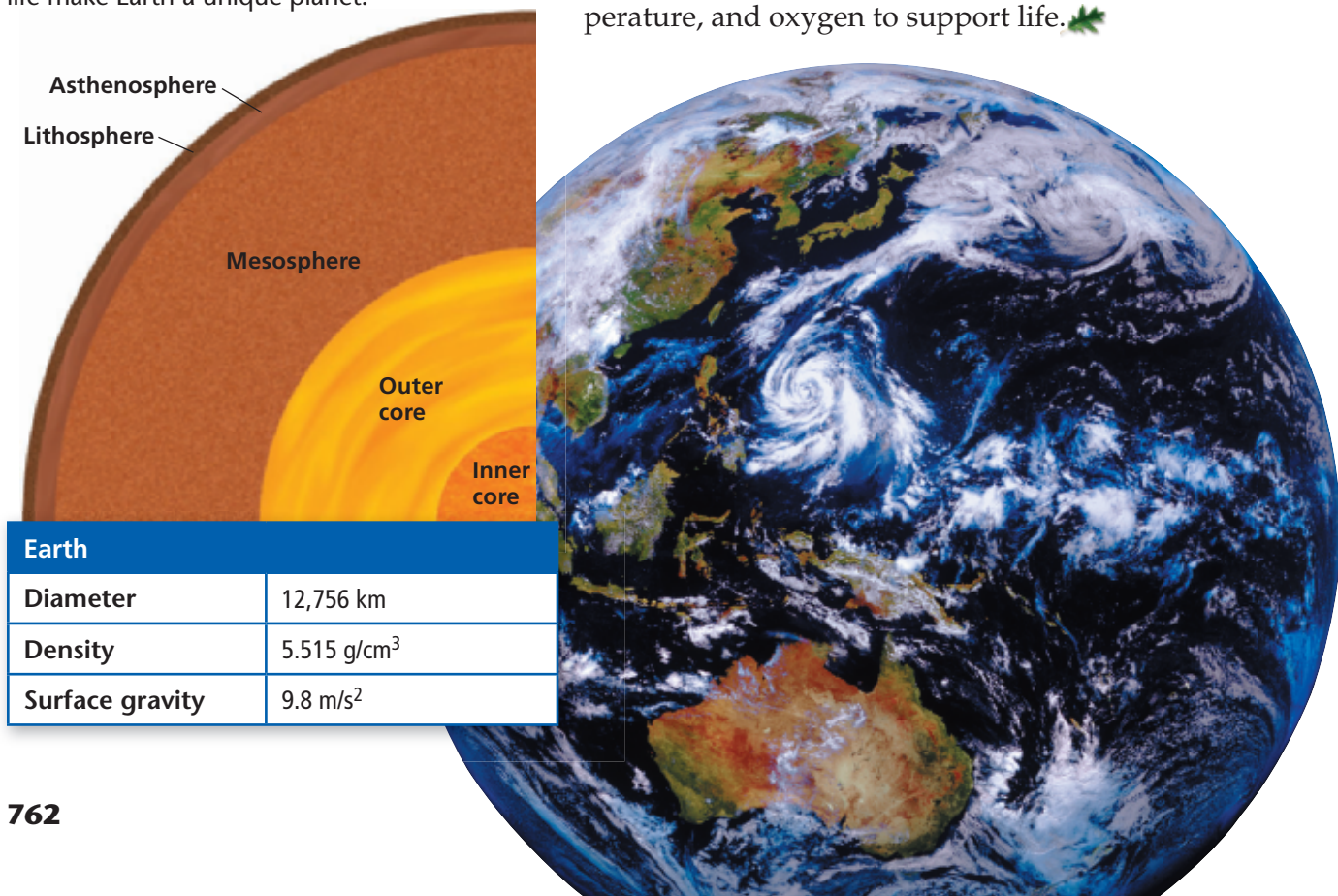
Water on Earth

Earth’s unique atmosphere and distance from the sun allow water to exist in a liquid state. Mercury and Venus are so close to the sun that any liquid water on those planets would boil. The outer planets are so far from the sun that water freezes. Earth is the only planet known to have oceans of liquid water, as shown in **Figure 4**. However, scientists think that Jupiter’s moon Europa may have an ocean under its icy crust and that Saturn’s moon Enceladus may have underground lakes.

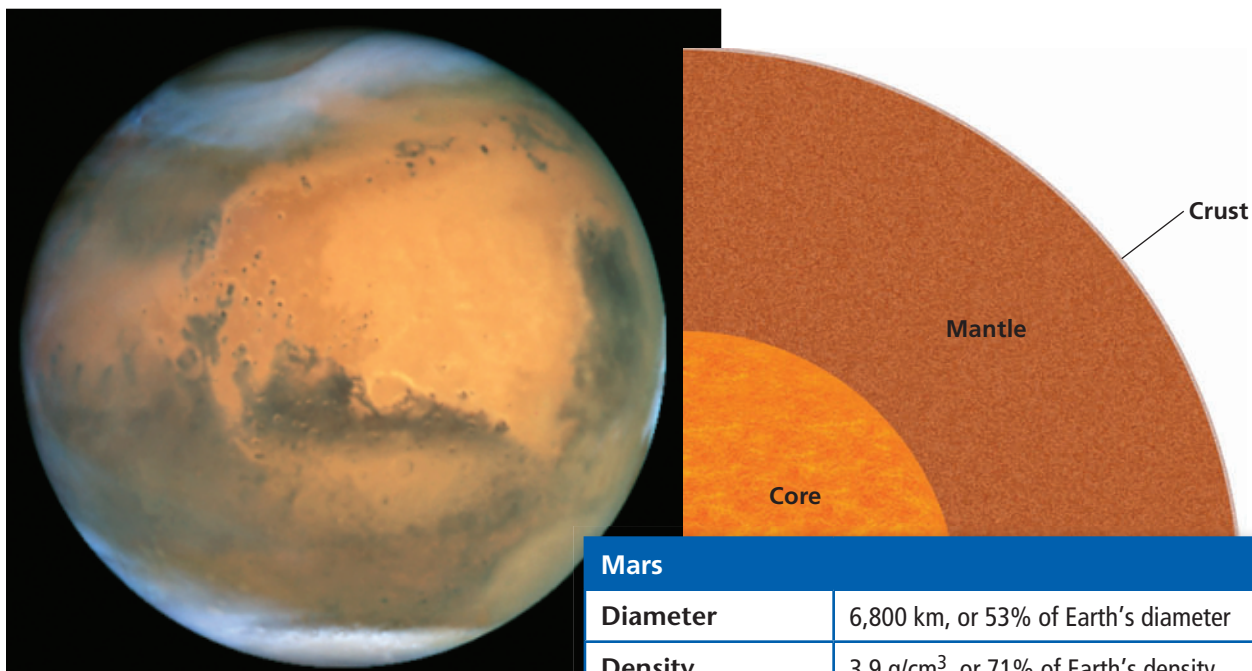
Life on Earth

Scientists theorize that as oceans formed on Earth, liquid water dissolved carbon dioxide from the atmosphere. Because of this process, carbon dioxide did not build up in the atmosphere and solar heat was able to escape. Thus, Earth maintained the moderate temperatures needed to support life. Plants and cyanobacteria contributed free oxygen to the atmosphere. Earth is the only known planet that has the proper combination of water, temperature, and oxygen to support life. ✿

Figure 4 Oceans of water and an atmosphere that can support life make Earth a unique planet.



Earth	
Diameter	12,756 km
Density	5.515 g/cm ³
Surface gravity	9.8 m/s ²



Mars	
Diameter	6,800 km, or 53% of Earth's diameter
Density	3.9 g/cm ³ , or 71% of Earth's density
Surface gravity	38% of Earth's surface gravity

Mars

Mars, shown in **Figure 5**, is the fourth planet from the sun. At an average distance of about 228 million kilometers from the sun, Mars is about 50% farther from the sun than Earth is. Its orbital period is 687 days, and it rotates on its axis every 24 h 37 min. Because its axis tilts at nearly the same angle that Earth's does, Mars's seasons are much like Earth's seasons.

Mars has been geologically active in its past, which is shown in part by the presence of massive volcanoes. A system of deep canyons also covers part of the surface. Valles Marineris is a series of canyons that is as long as the United States is wide—4,000 km. The canyon is thought to be a crack that formed in the crust as the planet cooled. It was later eroded by water.

Martian Volcanoes

Tharsis Montes is one of several volcanic regions on Mars. Volcanoes in this region are 100 times as large as Earth's largest volcano. The largest volcano on Mars is Olympus Mons, which is nearly 24 km tall. It is three times as tall as Mount Everest. At 550 km across, the base of Olympus Mons is about the size of Nebraska. Scientists think that the volcano has grown so large because Mars has no moving tectonic plates. So, Olympus Mons may have had a magma source for millions of years.

Whether Martian volcanoes are still active is a question scientists have yet to answer. A *Viking* landing craft detected two geological events that produced seismic waves. These events, called *marsquakes*, may indicate that volcanoes on Mars are active.

Reading Check Why are Martian volcanoes larger than Earth's volcanoes?

Figure 5 Mars is called the *Red Planet* because the oxidized rocks on the planet's surface give the planet a red color.

READING TOOLBOX

Word Origins

In English, *Olympus Mons* is "Mount Olympus." Look up *Mount Olympus* to see why it is an appropriate name for this particular formation on Mars.

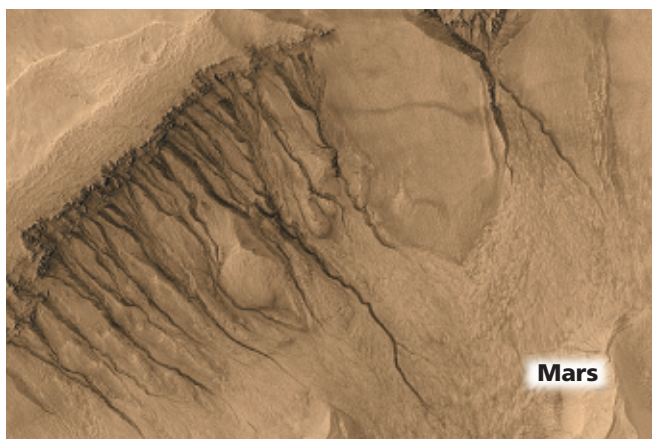


Figure 6 The images above compare the formation of gullies by possible liquid water runoff on Mars (left) with the formation of similar gullies at Mungo National Park in Australia on Earth (right). Mungo National Park is the site of a large lake that dried up more than 10,000 years ago.

Water on Mars

✦ The pressure and temperature of Mars’s atmosphere are too low for water to exist as a liquid on Mars’s surface. However, several NASA missions—such as the Mars rovers, *Spirit* and *Opportunity*, which landed on Mars in 2004—have found evidence that liquid water did exist on Mars’s surface in the past. Mars has many surface features that are characteristic of erosion by water, such as branching paths that look like gullies, as shown in **Figure 6**. Scientists think that other features on Mars might be evidence of vast flood plains produced by a volume of water equal to that of all five of Earth’s Great Lakes.

The surface temperature on Mars ranges from 20°C near the equator during the summer to as low as –130°C near the poles during the winter. Although most of the water on Mars is trapped in polar icecaps, data from the *Phoenix* lander confirmed in 2008 that water also exists as ice just below the Martian surface. If liquid water were to exist below Mars’s surface, the odds of life existing on Mars would dramatically increase. However, no solid evidence of life on Mars has been found. ✦

Section 3 Review

Key Ideas

1. **Explain** why Mercury has such drastically different temperatures during its day and during its night.
2. **Describe** the main ways in which Venus is similar to and different from Earth.
3. **Identify** the aspects that make Earth hospitable for life.
4. **Explain** why Mars’s volcanoes became so tall.
5. **Explain** why Mars does not have liquid water on its surface.
6. **Compare** the characteristics of the inner planets.

Critical Thinking

7. **Making Comparisons** Describe the difference between the greenhouse effect on Venus and the greenhouse effect on Earth.
8. **Understanding Relationships** As rock cools, it contracts. How could this fact explain the presence of Valles Marineris on Mars?

Concept Mapping

9. Use the following terms to create a concept map: *Mercury, Venus, Earth, Mars, terrestrial planet, Olympus Mons, liquid water, and Maat Mons.*

The Outer Planets

Key Ideas

- Identify the basic characteristics that make the outer planets different from terrestrial planets.
- Compare the characteristics of the outer planets.
- Explain why Pluto is now considered a dwarf planet.

Key Terms

gas giant
Kuiper Belt

Why It Matters

Objects beyond the outer planets hold clues to the origin of the solar system. But sending probes to this region is expensive.

The four planets farthest from the sun are called the *outer planets*. They are separated from the inner planets by a ring of debris called the *asteroid belt*. Jupiter, Saturn, Uranus, and Neptune, which are shown in **Figure 1**, are also called **gas giants** because they are large planets that have deep, massive atmospheres made mostly of gas. Uranus and Neptune have more frozen gases and are also known as ice giants. Usually found past the orbit of Neptune is Pluto. Prior to 2006, Pluto was considered to be the most distant outer planet. However, in August of 2006, Pluto was reclassified as a *dwarf planet*.

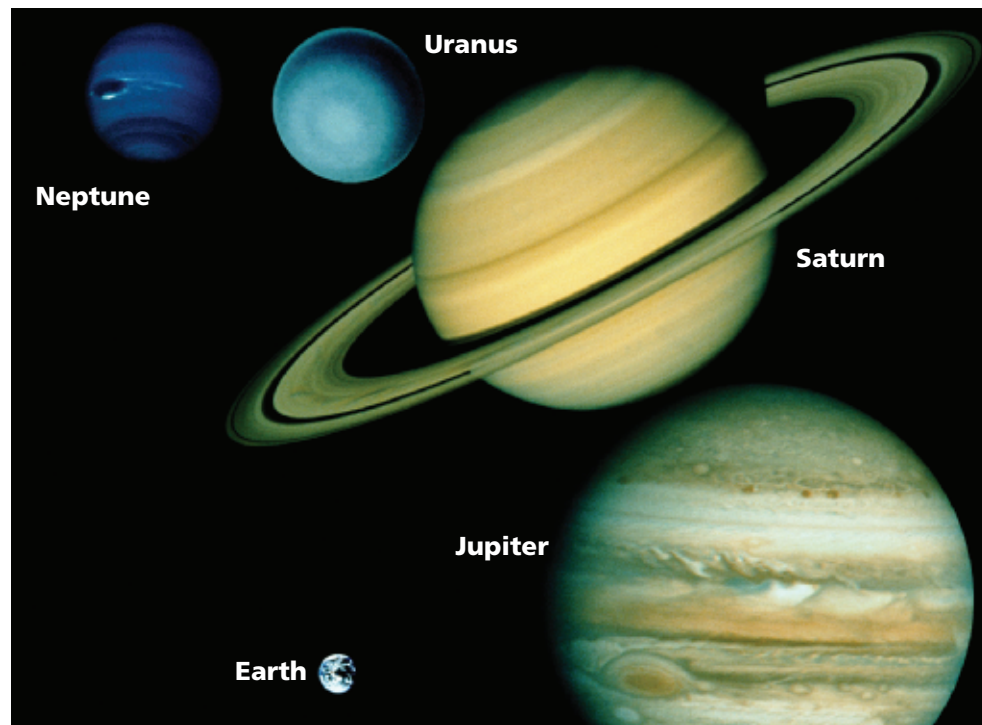
Gas Giants

Although the gas giants are much larger and more massive than the terrestrial planets, the gas giants are much less dense than the terrestrial planets. Unlike the terrestrial planets, the gas giants did not lose their original gases during their formation. Their large masses give them a huge amount of gravity, which helps them retain the gases. Each of the gas giants has a thick atmosphere that is made mostly of hydrogen and helium gases. A cloud layer prevents scientists from directly observing more than the topmost part of the atmosphere of the gas giants. But each planet probably has a core made of rock and metals.

Although Saturn's rings may be the most impressive, all four gas giants have ring systems that are made of dust and icy debris that probably came from comets or other bodies.

gas giant a planet that has a deep, massive atmosphere, such as Jupiter, Saturn, Uranus, or Neptune

Figure 1 The four gas giants are much larger than Earth, which is the terrestrial planet shown here at the lower left.



SciLINKS

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Topic: Outer Planets
Code: HQX1091

Jupiter

Jupiter, shown in **Figure 2**, is the fifth planet from the sun and is by far the largest planet in the solar system. Its mass is more than 300 times that of Earth and is twice that of all the other planets combined. Jupiter's orbital period is almost 12 years. Jupiter rotates on its axis faster than any other planet rotates—once every 9 h 50 min. Jupiter has at least 63 moons, 4 of which are the size of small planets. It also has several thin rings that are made up of millions of particles.

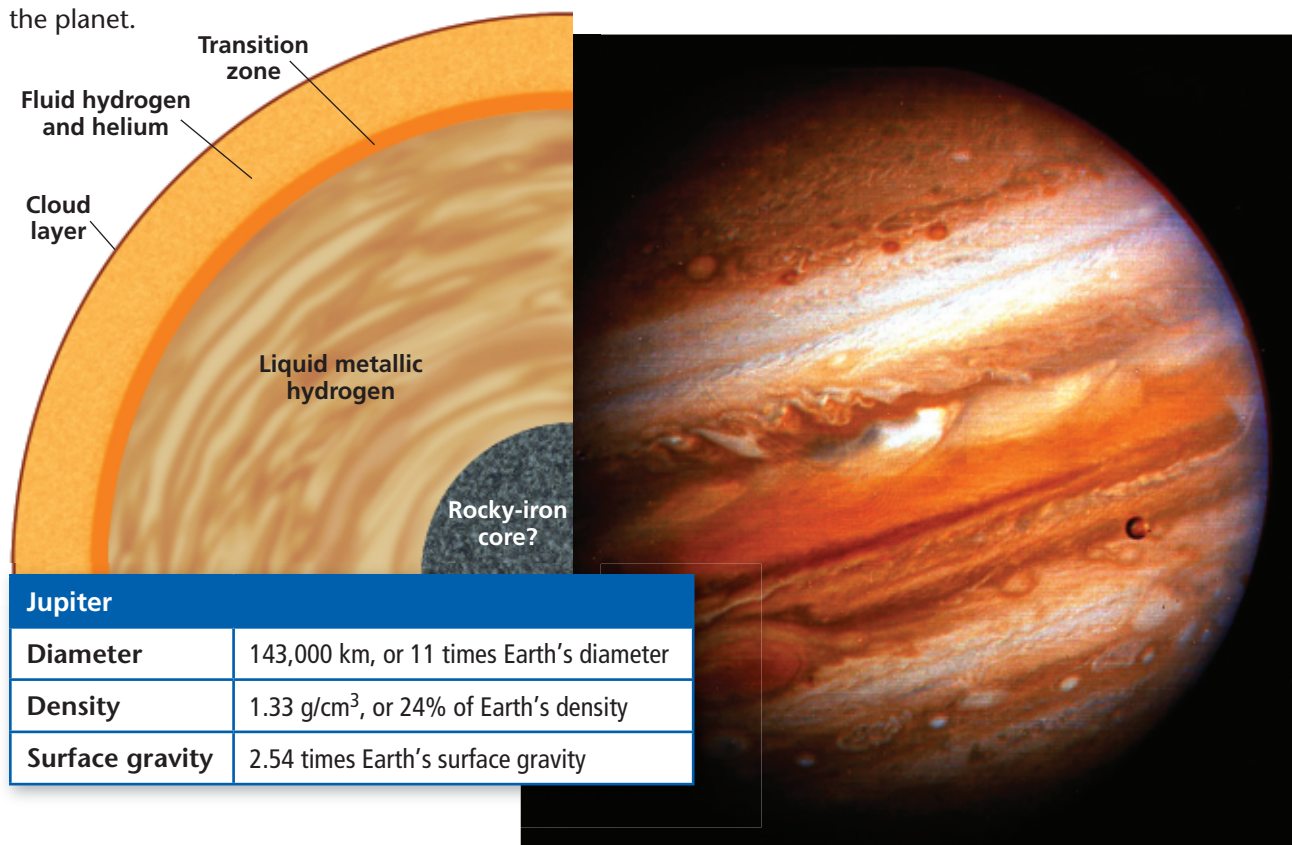
Jupiter's Atmosphere

Hydrogen and helium make up 92% of Jupiter, so Jupiter's composition is much like the sun's. However, when Jupiter formed about 4.6 billion years ago, it did not have enough mass to allow nuclear fusion to begin. So, Jupiter never became a star.

The alternating light and dark bands on its surface make Jupiter unique in our solar system. Orange, gray, blue, and white bands spread out parallel to the equator. The colors suggest the presence of organic molecules mixed with ammonia, methane, and water vapor. Jupiter's rapid rotation causes these gases to swirl around the planet and form the bands. The average temperature of Jupiter's outer atmospheric layers is -160°C . Jupiter has lightning storms and thunderstorms that are much larger than those on Earth.

 **Reading Check** Why didn't Jupiter become a star?

Figure 2 Jupiter is easily identified by its large size and alternating light and dark bands. One of Jupiter's larger moons can be seen in front of the planet.



Jupiter	
Diameter	143,000 km, or 11 times Earth's diameter
Density	1.33 g/cm ³ , or 24% of Earth's density
Surface gravity	2.54 times Earth's surface gravity

Weather and Storms on Jupiter

Jupiter's most distinctive feature is its *Great Red Spot*, shown in **Figure 3**. The Great Red Spot is a giant rotating storm, similar to a hurricane on Earth, that has been raging for at least several hundred years. Several other oval spots, or storms, can be seen on Jupiter, although they are usually white. Sometimes, the smaller storms are swallowed up by the larger ones. While storms are common on Jupiter's surface, only a few of the largest storms persist for a long time.

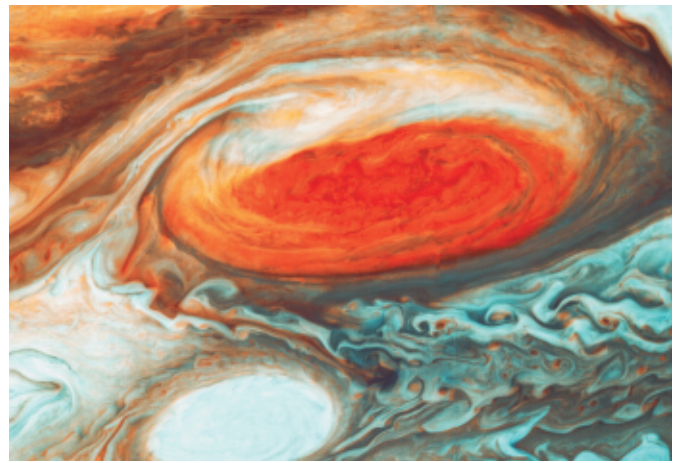


Figure 3 Jupiter's Great Red Spot is an ongoing, massive, hurricane-like storm that is about twice the diameter of Earth.

A probe dropped by the *Galileo* spacecraft measured wind speeds of up to 540 km/h on Jupiter. Because winds are caused by temperature differences, scientists have concluded that Jupiter's internal heat affects the planet's weather more than heat from the sun does. From Earth, even using a small telescope, you can see bands of clouds on Jupiter. These bands, which vary depending on latitude, show regions of different wind speeds.

Jupiter's Interior

Jupiter's large mass causes the temperature and pressure in Jupiter's interior to be much greater than they are inside Earth. The intense pressure and temperatures as high as 30,000 °C have changed Jupiter's interior into a sea of liquid, metallic hydrogen. Electric currents in this hot liquid may be the source of Jupiter's enormous magnetic field. Scientists think that Jupiter has a solid, rocky, iron core at its center.

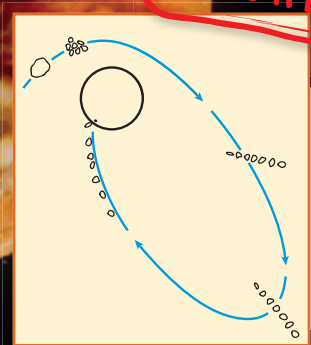
Academic Vocabulary

distinctive (di STINGK tiv) notable, distinguishing

Why It Matters

What Happens When a Comet Hits a Planet?

Nobody had ever witnessed a collision between a comet and a planet in all of human history. That changed in 1994 when comet Shoemaker-Levy collided with Jupiter.



The comet was trapped in July 1992, and its fragments collided two years later.

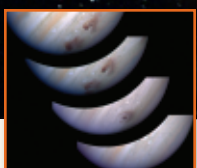


CRITICAL THINKING

Why did the comet fragments leave no impact craters when they collided with Jupiter?



When it was trapped by Jupiter's gravity, the comet broke into fragments in a formation described as a "string of pearls."



The fragments vaporized in Jupiter's atmosphere.

Saturn

Saturn, shown in **Figure 4**, is the sixth planet from the sun and has an orbital period of 29.5 years. Because it is so far from the sun, Saturn is very cold and has an average cloud-top temperature of -176°C . Saturn has at least 60 moons, and additional small moons continue to be discovered. Its largest moon, Titan, which has a diameter of 5,150 km, is half the size of Earth.

Saturn, like Jupiter, is made almost entirely of hydrogen and helium and has a rocky, iron core at its center. However, Saturn is much less dense than Jupiter. In fact, Saturn is the least dense planet in the solar system.

Saturn's Bands and Rings

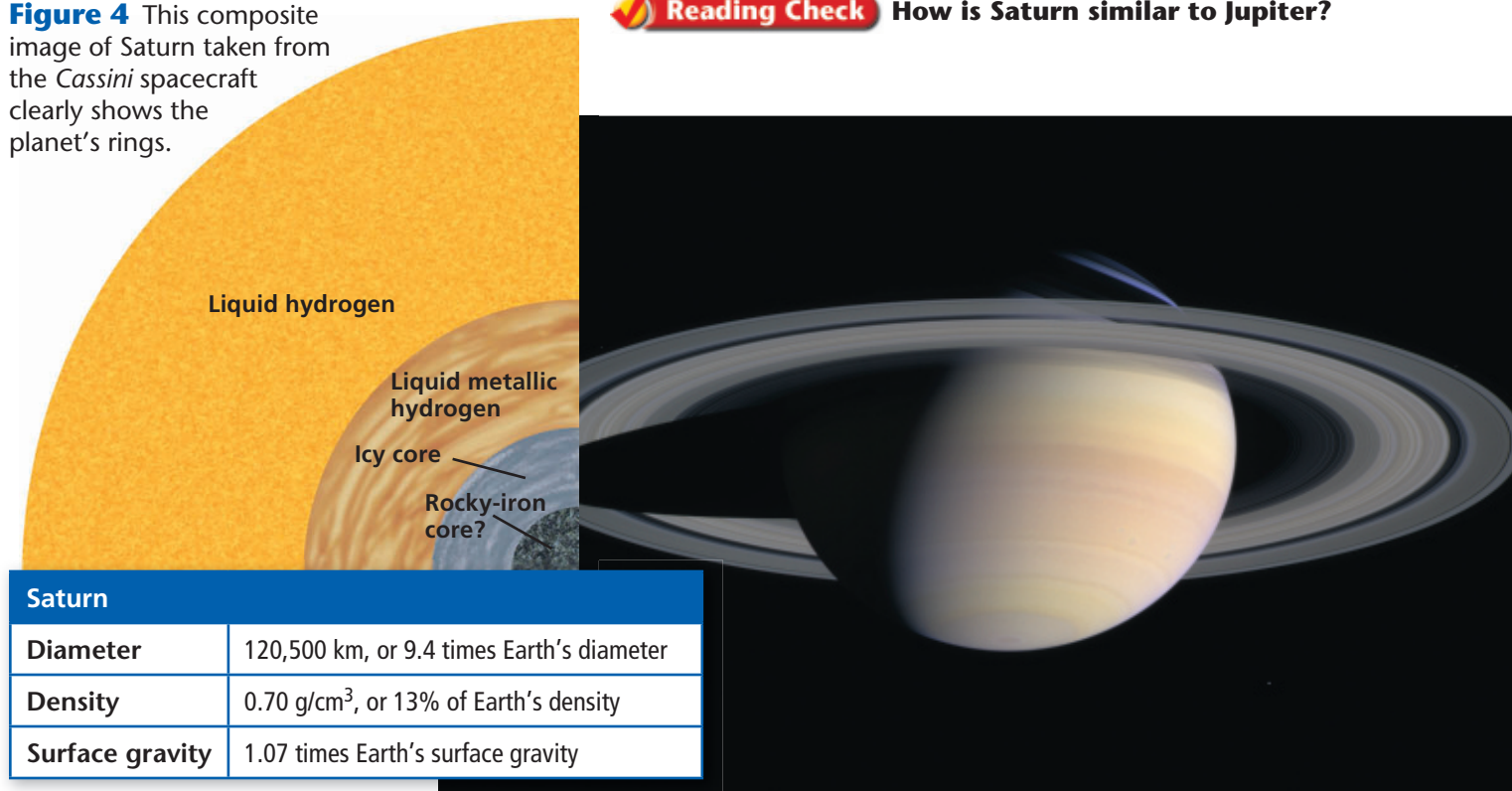
Saturn is known for its rings, which are two times the planet's diameter. While the other gas giants also have rings, Saturn has the most complex and extensive system of rings. The rings are made of billions of dust and ice particles. Most of the ring debris probably came from comets or other bodies.

Like Jupiter, Saturn also has bands of colored clouds that run parallel to its equator. These bands are caused by Saturn's rapid rotation. Saturn rotates on its axis about every 10 h 30 min. This rapid rotation, paired with Saturn's low density, causes Saturn to bulge at its equator and to flatten at its poles.

Scientists are learning more about Saturn and its moons from NASA's *Cassini* spacecraft, which reached Saturn on July 1, 2004. *Cassini* also carried the European Space Agency's *Huygens* probe, which landed on Titan, Saturn's largest moon.

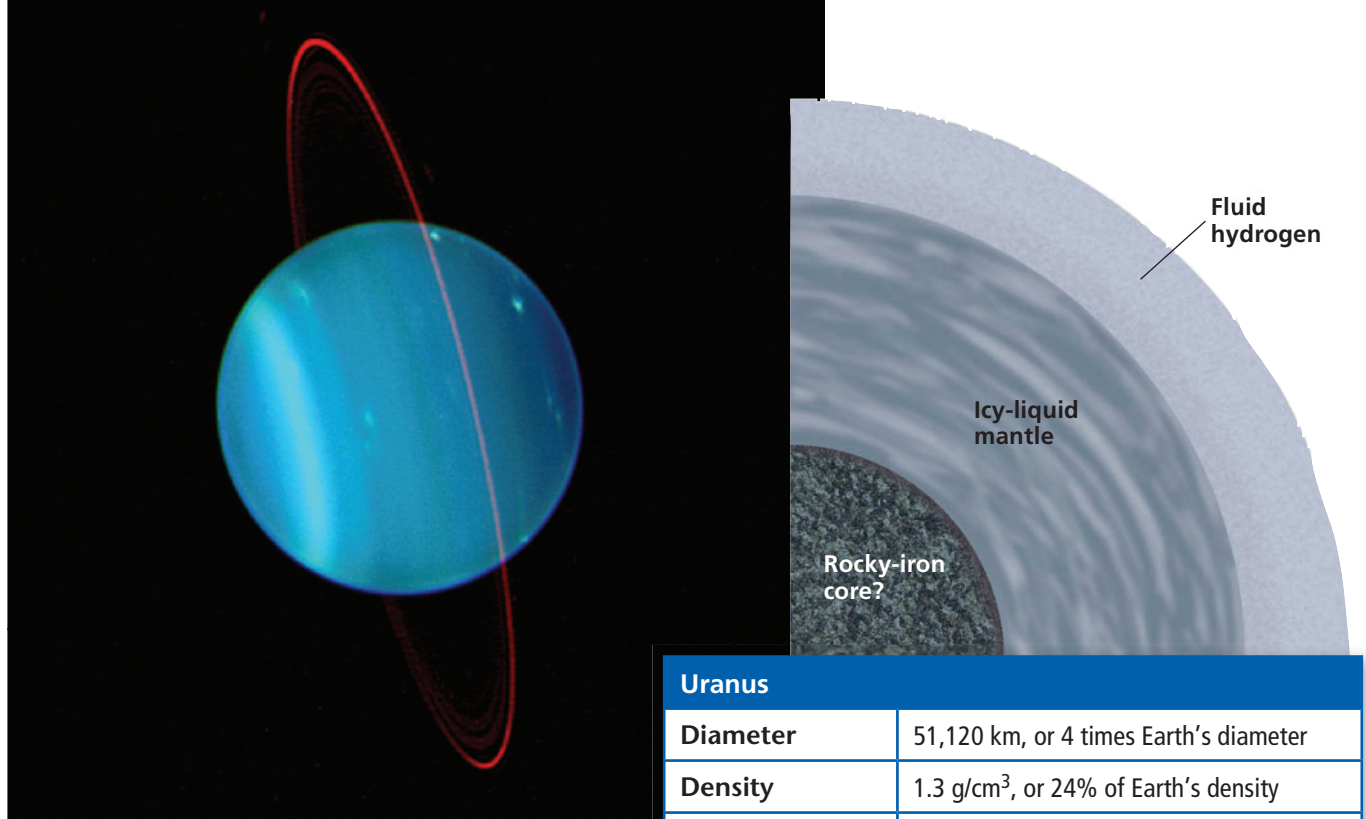
Figure 4 This composite image of Saturn taken from the *Cassini* spacecraft clearly shows the planet's rings.

 **Reading Check** How is Saturn similar to Jupiter?



Saturn

Diameter	120,500 km, or 9.4 times Earth's diameter
Density	0.70 g/cm^3 , or 13% of Earth's density
Surface gravity	1.07 times Earth's surface gravity



Uranus	
Diameter	51,120 km, or 4 times Earth's diameter
Density	1.3 g/cm ³ , or 24% of Earth's density
Surface gravity	91% of Earth's surface gravity

Uranus

Uranus, shown in **Figure 5**, is the seventh planet from the sun and the third-largest planet in the solar system. William Herschel discovered Uranus in 1781. Because Uranus is nearly 3 billion kilometers from the sun, Uranus is a difficult planet to study. But the *Hubble Space Telescope* has taken images that show changes in Uranus's atmosphere. Uranus has at least 27 moons and at least 12 thin rings. Its orbital period is almost 84 years.

Uranus's Rotation

The most distinctive feature of Uranus is its unusual orientation. Most planets, including Earth, rotate with their axes perpendicular to their orbital planes as they revolve around the sun. However, Uranus's axis is almost parallel to the plane of its orbit. The rotation rate of Uranus was not discovered until 1986, when *Voyager 2* passed by Uranus. Astronomers were then able to determine that Uranus rotated once about every 17 h.

Uranus's Atmosphere

Like the other gas giants, Uranus has an atmosphere that contains mainly hydrogen and helium. The blue-green color of Uranus indicates that the atmosphere also contains significant amounts of methane. The average cloud-top temperature of Uranus is -214°C . However, astronomers believe that the planet's temperature is much higher below the clouds. There may be a mixture of liquid water and methane beneath the atmosphere. Scientists also think that the center of Uranus, which has a temperature of approximately $7,000^{\circ}\text{C}$, is a core of rock and melted elements.

Figure 5 This exaggerated-color image from the *Hubble Space Telescope* shows Uranus, two of its moons, and some of its rings.

Neptune

Neptune, shown in **Figure 6**, is the eighth planet from the sun and is similar to Uranus in size and mass. Neptune's orbital period is nearly 164 years, and the planet rotates about every 16 h. Neptune has at least 13 moons and six rings.

The Discovery of Neptune

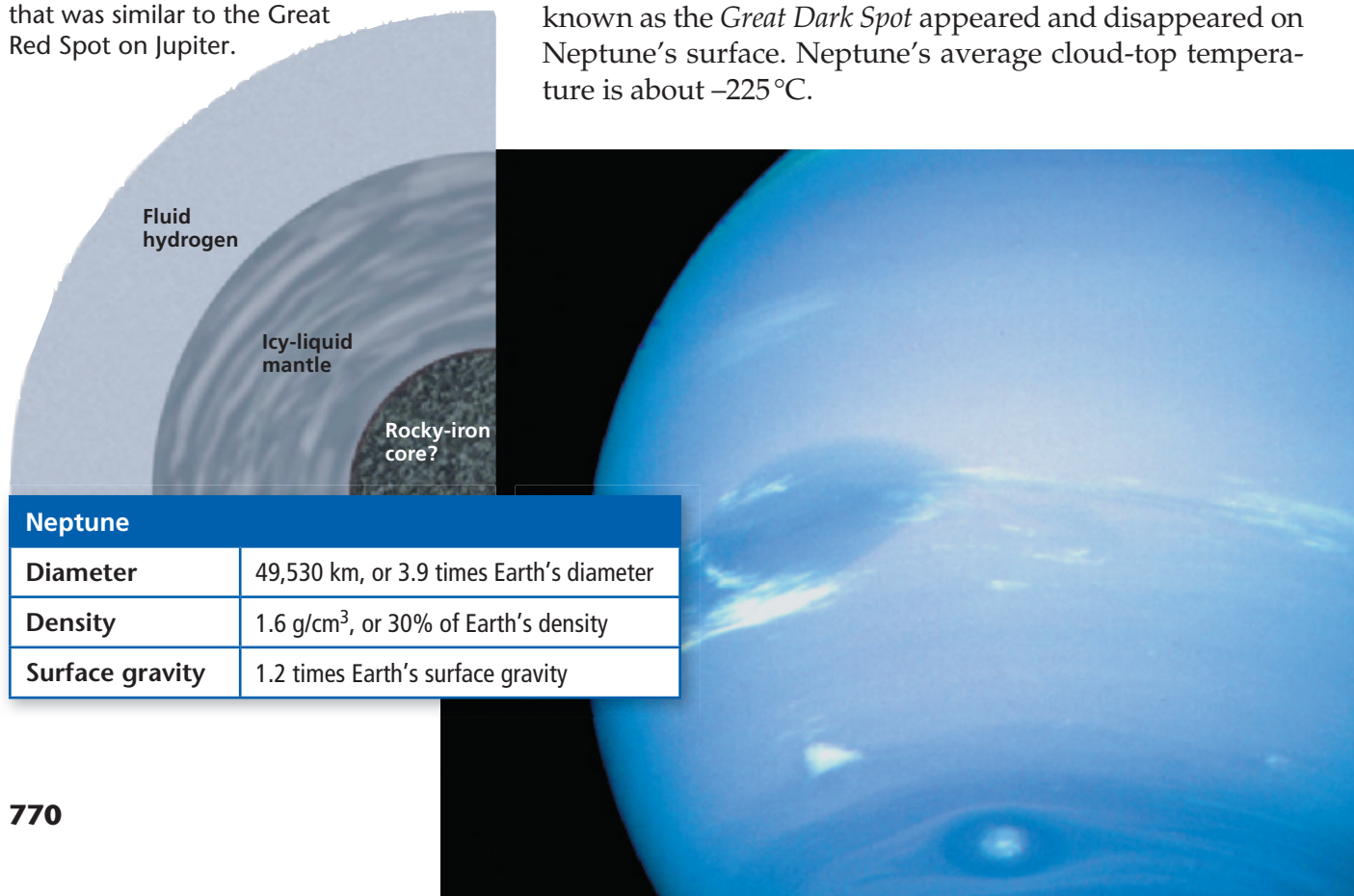
Neptune's existence was predicted before Neptune was actually discovered. After Uranus was discovered, astronomers noted variations from its calculated orbit. They suspected that the gravity of an unknown planet was responsible for the variation. In the mid-1800s, John Couch Adams, an English mathematician, and Urbain Leverrier, a French astronomer, independently calculated the position of the unknown planet. A German astronomer, Johann Galle, discovered a bluish-green disk where Leverrier had predicted the planet would be. Astronomers named the planet Neptune after the Roman god of the sea.

Neptune's Atmosphere

Data from the *Voyager 2* spacecraft indicate that Neptune's atmosphere is made up mostly of hydrogen, helium, and methane. Neptune's upper atmosphere contains some white clouds of frozen methane. These clouds appear as continually changing bands between the equator and the poles of Neptune.

Images taken by *Voyager 2*, the *Hubble Space Telescope*, and earth-bound telescopes indicate that Neptune has an active weather system. Neptune has the solar system's strongest winds, which exceed 1,000 km/h. A storm that is the size of Earth and that is known as the *Great Dark Spot* appeared and disappeared on Neptune's surface. Neptune's average cloud-top temperature is about -225°C .

Figure 6 This Great Dark Spot on Neptune was a giant storm that was similar to the Great Red Spot on Jupiter.



Neptune

Diameter	49,530 km, or 3.9 times Earth's diameter
Density	1.6 g/cm ³ , or 30% of Earth's density
Surface gravity	1.2 times Earth's surface gravity



Figure 7 This artist drawing illustrates the largest known trans-Neptunian objects. Note that Pluto, once considered one of the nine planets, is not the largest.

Objects Beyond Neptune

Pluto was discovered in 1930. Until 2006, it was known as the ninth planet. Now, it is defined as a dwarf planet. A *dwarf planet* is any object that orbits the sun, is round because of its own gravity, has not cleared the region around its orbit, and is not a satellite of another planet.

Pluto orbits the sun in an unusual elongated and tilted ellipse. Pluto is usually far beyond Neptune, but it is closer to the sun than Neptune is for about 20 years out of its 248-year orbital period. With a diameter of 2,302 km, Pluto is smaller than Earth's moon. Astronomers think that Pluto is made up of frozen methane, rock, and ice and has an average temperature of -235°C . Infrared images show that Pluto has extensive methane icecaps and a very thin nitrogen atmosphere. It also has three moons, one of which, named Charon (KER uhn), has a diameter more than half that of Pluto.

Kuiper-Belt Objects

In recent years, scientists have discovered hundreds of objects in our solar system beyond Neptune's orbit. These objects are called *trans-Neptunian objects* (TNOs). Some of these TNOs are similar to Pluto in size and composition, as shown in **Figure 7**, but most are simply small chunks of ice. TNOs exist in a region beyond Neptune's orbit called the **Kuiper Belt** (KIE puhR BELT). Scientists think that these bodies are the remnants of material that formed the early solar system.

Like Pluto, Eris, Makemake (MAH kay MAH kay), and Haumea (HAH oo may uh) are trans-Neptunian dwarf planets or *plutoids*. The other large TNOs have not been classified as such, but may eventually be considered as meeting the definition.

 **Reading Check** Where is the Kuiper Belt located?

READING TOOLBOX

Word Origins

Eris was a Greek goddess, and Sedna was an Inuit goddess. Quaoar was a god of the Native American Tongva people. Look up these names, and find why they were chosen as names of objects beyond Neptune's orbit.

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

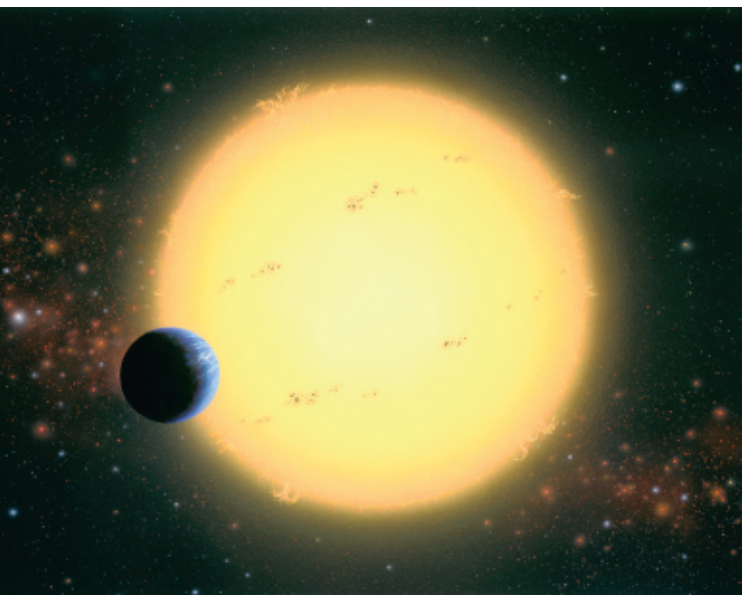


Figure 8 This illustration shows an artist's idea of a Jupiter-sized exoplanet in the foreground. This exoplanet orbits a sun-like star called HD209458, which is located 150 light years from Earth.

Exoplanets

Until the 1990s, all the planets that astronomers had discovered were in Earth's solar system. Since then, however, several hundred planetlike objects have been attributed to stars other than Earth's sun. Because these objects circle stars other than Earth's sun, they are called *exoplanets*. The prefix *exo-* means "outside."

Figure 8 shows an artist's rendition of an exoplanet. Most known exoplanets orbit stars that are similar to Earth's sun. Therefore, the existence of exoplanets leads some scientists to wonder if life could exist in another solar system.

Because of their size and distance, exoplanets have only recently been directly observed with telescopes. Most exoplanets can be detected only because their gravity tugs on stars that they orbit. When scientists study some distant stars, they notice that the light coming from the stars shifts in wavelength. This shifting could be explained by the stars' movement slightly toward and then away from Earth. Scientists know that the gravity of an object that cannot be seen can affect a star's movement. In these cases, that object is most likely an exoplanet that orbits the star.

Most of the exoplanets that have been identified are larger than Uranus, but gradually astronomers are discovering exoplanets that are closer to Earth in mass. One may even be the right temperature to support life as we know it. Many exoplanets, though more massive than Jupiter, are closer to their stars than Mercury is to Earth's sun. From studying these many solar systems, scientists hope to learn more about the formation and basic arrangement of solar systems.

Section 4 Review

Key Ideas

1. **Explain** what makes Jupiter similar to the sun.
2. **Compare** the characteristics of Jupiter, Saturn, Uranus, and Neptune.
3. **Compare** Jupiter's Great Red Spot with weather on Earth.
4. **Describe** the way in which the tilt of the axis of Uranus's rotation is unusual.
5. **Explain** how Pluto differs from the outer planets of the solar system.
6. **Summarize** the features of objects in the Kuiper Belt.
7. **Describe** what scientists know about exoplanets, planetlike objects outside the solar system.

Critical Thinking

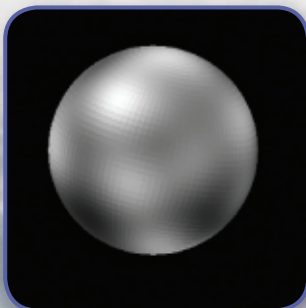
8. **Making Comparisons** How are the compositions of the gas giants similar to the composition of the sun?
9. **Making Inferences** Why is Pluto not considered a planet even though Neptune is sometimes farther from the sun than Pluto is?
10. **Evaluating Conclusions** Should scientists reconsider Pluto to be a planet? Explain your answer.

Concept Mapping

11. Use the following terms to create a concept map: *outer planet, Jupiter, Saturn, Uranus, Neptune, Pluto, gas giant, Kuiper Belt, and Great Red Spot.*

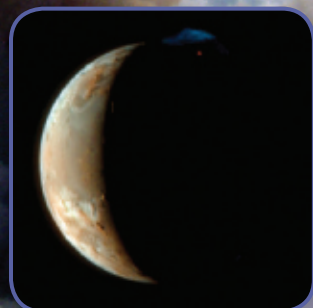
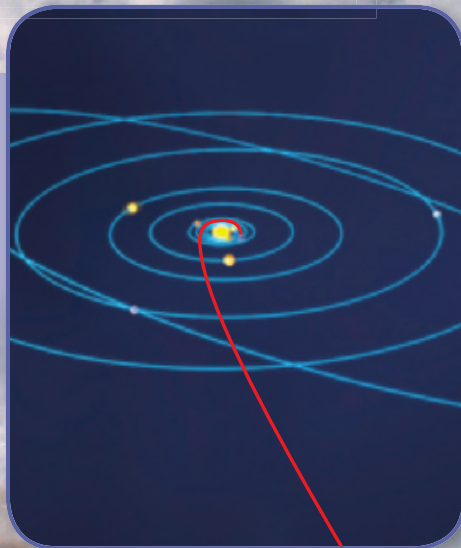
New Horizons for Pluto

The *New Horizons* spacecraft, on its way to Pluto and the nearby region of icy, rocky solar system bodies called the Kuiper Belt, is the fastest traveler in history. However, despite a speed of 75,000 km/h, the craft will take nine years to reach Pluto in 2015. According to Deputy Associate Administrator for NASA's Science Mission Directorate, Dr. Colleen Hartman, "What we know about Pluto could be written on the back of a postage stamp. After this mission, we'll be able to fill textbooks with new information."



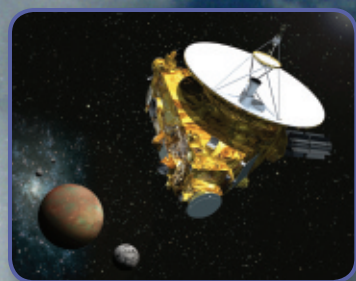
This photo, from 1994, was the first image of Pluto's surface. Taken by the Hubble telescope, it shows 12 distinct surface regions of light and darkness.

The piano-sized craft operates on less power than two 100-watt bulbs. In 2007, it used the gravity of Jupiter to help propel it toward Pluto.



During its Jupiter flyby, *New Horizons* photographed this eruption on Io, one of Jupiter's moons. The volcanic plume rises 320 km above the surface.

SCIENCE & SOCIETY



The *New Horizons* spacecraft

YOUR TURN

CRITICAL THINKING

New Horizons was launched when Pluto was still called a planet. Should the mission have been cancelled? Why or why not?

ONLINE RESEARCH

Find out where *New Horizons* is right now.

What You'll Do

- › **Create** a model that demonstrates the formation of impact craters.
- › **Analyze** how an object's speed and projectile angle affect the impact crater that the object forms on planets and moons.

What You'll Need

marble, large (1)
marbles, small (5)
marker
meter stick
plaster of Paris
protractor
scissors
shoe box
tape, masking
toothpicks (6)
tweezers

Safety



Crater Analysis

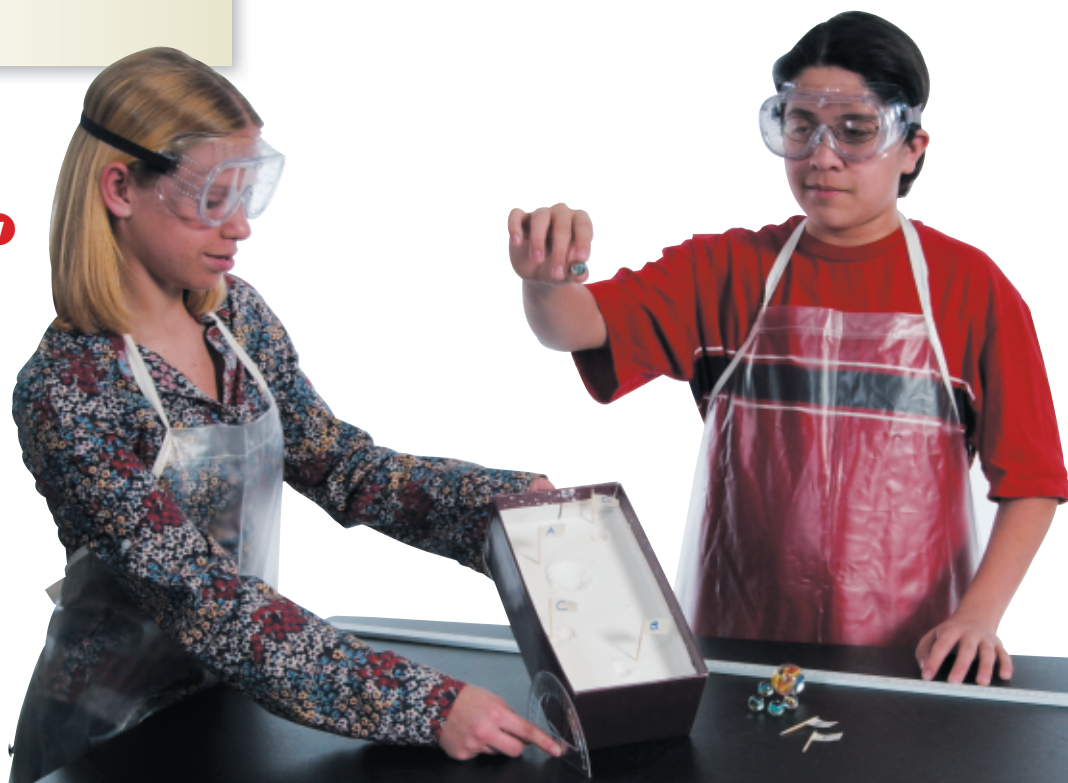
All of the inner planets—Mercury, Venus, Earth, and Mars—have many features in common. They are all made of mostly solid rock and have metallic cores. They have no rings and have from zero to two moons each. And they have bowl-shaped depressions called *impact craters*. Impact craters are caused by collisions between the planets and rocky objects that travel through space. Most of these collisions took place during the formation of the solar system.

Mercury's entire surface is covered with these craters, while very few craters are still evident on the surface of Earth. Many of the moons of the inner and outer planets are also heavily cratered. In this lab, you will experiment with making craters to discover the effect of speed and projectile angle on the way craters form.

Procedure

- 1 Place the top of a toothpick in the center of a piece of masking tape that is 6 cm long. Fold the tape in half around the toothpick to form a "small flag" and "flagpole." On the flag, write the letter *A*. Repeat this step for the other toothpicks, and label them with the letters *B* through *F*.
- 2 Mix plaster of Paris with water, according to instructions for making plaster of Paris. Spread your mixture in the bottom of the shoe box. Make your plaster layer about 4 cm thick. The surface should be as smooth as possible.

Step 7



- 3 Allow the plaster to dry until it is no longer soupy, but not yet rigid.
- 4 Drop a large marble onto the plaster from a height of 50 cm above the surface. Quickly remove the marble with tweezers, but do not damage the crater that formed. Place flag A next to the crater to label the crater.
- 5 Repeat step 4 by using a small marble dropped from a height of 50 cm and another small marble dropped from a height of 25 cm. Use the flags to label craters B (50 cm drop) and C (25 cm drop).
- 6 Repeat step 4 by using a small marble dropped from a height of 1 m. Label the crater D.
- 7 Using a protractor as a guide, have your partner tilt the box at a 30° angle to the table. Be sure your partner holds the box steady. Then, drop a small marble vertically from a height of 50 cm. Label the crater E.
- 8 Repeat step 7 by using an angle of 45°. Label the crater F.
- 9 Allow the plaster of Paris to harden. Write a description of each crater and the surrounding area.



Step 6

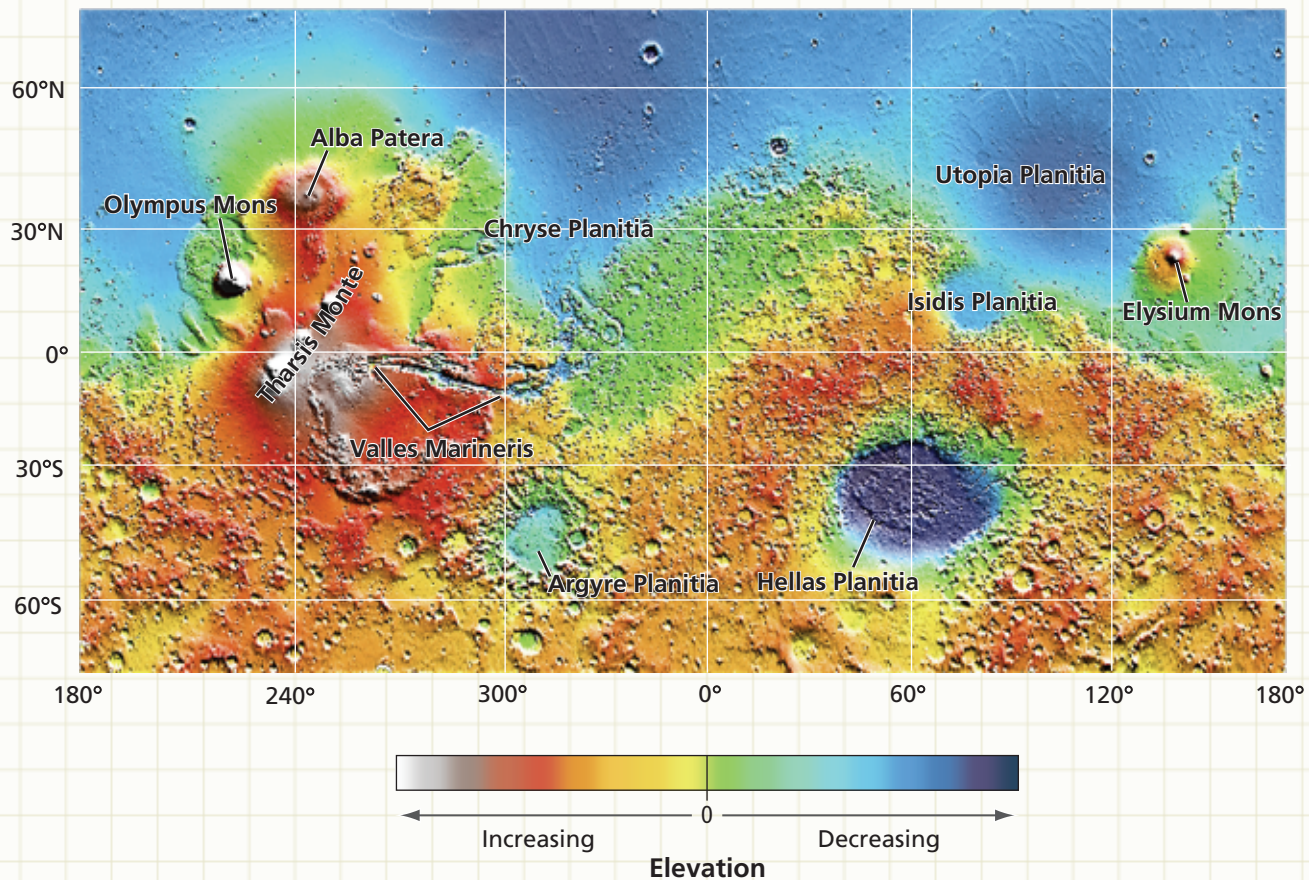
Analysis

1. **Examining Data** Which crater was formed by the marble that had the highest velocity? What is the effect of velocity on the characteristics of the crater formed?
2. **Explaining Events** Study the shapes of craters B, E, and F. How did the angle of the plaster of Paris affect the shape of the craters that formed?
3. **Making Comparisons** Compare craters A, B, and D. How do they differ from each other? What caused this difference? Is the difference in the masses of the objects a factor? Explain your answer.

Extension

Applying Conclusions Find a map of the surface craters on one of the terrestrial planets. Identify craters that were made by different angles of impact. Label the craters on the diagram, and present your findings to the class.

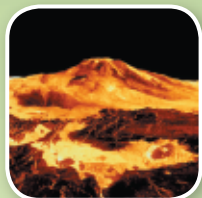
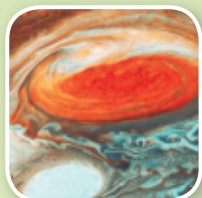
MOLA Map of Mars



Map Skills Activity

The above map shows the relative elevation of surface features on Mars's surface. The number 0 on the elevation scale marks the average elevation at the equator. This map was created from data collected by the Mars Orbiter Laser Altimeter (MOLA) on the *NASA Mars Global Surveyor*. Use the map to answer the questions below.

- Analyzing Data** Estimate the longitude and latitude of Elysium Mons.
- Using a Key** Identify three features that have elevations below 0. Identify three features that have elevations above 0.
- Comparing Areas** In general, which pole on Mars, the north pole or south pole, has higher elevations?
- Using a Key** Which feature, Isidis Planitia or Argyre Planitia, has a higher elevation?
- Making Comparisons** Which feature, Hellas Planitia or Olympus Mons, would most likely be a volcano?
- Using a Key** Estimate the distance between Olympus Mons and Elysium Mons in degrees of longitude.
- Inferring Relationships** Based on what you have learned from the map, what type of features do you think the words *planitia* and *mons* refer to?

Section 1**Section 2****Section 3****Section 4****Key Ideas****Formation of the Solar System**

- The solar system formed from a rotating and contracting region of gas and dust about 5 billion years ago.
- The planets formed from collisions of smaller bodies called *planetesimals*.
- Earth's land and atmosphere formed by differentiation. Oceans formed as water vapor in the atmosphere condensed and fell.

Models of the Solar System

- Ptolemy proposed an Earth-centered model of the universe. Copernicus proposed a sun-centered model.
- Kepler's first law states that orbits of planets are ellipses with the sun at one focus. The second law states that planets closer to the sun travel faster than those farther away. The third law relates a planet's average distance from the sun to the time it takes to make one orbit.
- Newton used the idea of inertia to explain Kepler's laws.

The Inner Planets

- The four inner (terrestrial) planets consist mainly of solid rock. Their surfaces show cratering, and they have metallic cores.
- The terrestrial planets are denser and smaller than the gas giants. Only Earth and Mars have moons. All but Mercury have notable atmospheres.
- Liquid water and an oxygen-enriched atmosphere enable Earth to sustain life.

The Outer Planets

- The outer planets lack a solid surface and are much less dense and much larger than the terrestrial planets.
- The outer planets have rings and many moons, as well as atmospheres rich with hydrogen and helium. Unlike the other outer planets, Uranus's axis of rotation is almost parallel to the plane of its orbit.
- Pluto is considered a dwarf planet because astronomers have reclassified objects of the solar system, and Pluto now fits the definition of a dwarf planet.

Key Terms

solar system, p. 749
planet, p. 749
solar nebula, p. 749
planetesimal, p. 750

eccentricity, p. 756
orbital period, p. 757
inertia, p. 758

terrestrial planet, p. 759

gas giant, p. 765
Kuiper Belt, p. 771

- 1. Chain-of-Events Chart** Make a chain-of-events chart to describe why the outer planets have very different characteristics from those of the inner planets.



USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *inertia*
3. *terrestrial planet*
4. *Kuiper Belt*

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

5. *Kuiper belt* and *orbital period*
6. *planet* and *planetesimal*
7. *terrestrial planet* and *gas giant*
8. *solar nebula* and *solar system*

UNDERSTANDING KEY IDEAS

9. Copernicus's model of the solar system is
 - a. geocentric.
 - b. lunocentric.
 - c. ethnocentric.
 - d. heliocentric.
10. Kepler's first law states that each planet orbits the sun in a path called a(n)
 - a. ellipse.
 - b. circle.
 - c. epicycle.
 - d. period.
11. The most distinctive feature of Jupiter is its
 - a. Great Red Spot.
 - b. Great Dark Spot.
 - c. ring.
 - d. elongated orbit.
12. The planet that has an axis of rotation that is almost parallel to the plane of its orbit is
 - a. Venus.
 - b. Jupiter.
 - c. Uranus.
 - d. Neptune.
13. The tilt of the axis of Mars is nearly the same as that of
 - a. Mercury.
 - b. Venus.
 - c. Earth.
 - d. Jupiter.

14. The planet that rotates faster than any other planet in the solar system is
 - a. Earth.
 - b. Jupiter.
 - c. Uranus.
 - d. Venus.
15. Kepler's law that describes how fast planets travel at different points in their orbits is called the law of
 - a. ellipses.
 - b. equal speeds.
 - c. equal areas.
 - d. periods.
16. All the outer planets rotate with their axes perpendicular to their orbital planes *except*
 - a. Saturn.
 - b. Jupiter.
 - c. Neptune.
 - d. Uranus.
17. The first atmosphere of Earth contained a large amount of
 - a. helium.
 - b. oxygen.
 - c. carbon dioxide.
 - d. methane.
18. The hypothesis that states that the sun and the planets developed out of the same cloud of gas and dust is called the
 - a. Copernicus hypothesis.
 - b. solar hypothesis.
 - c. nebular hypothesis.
 - d. Galileo hypothesis.
19. In the process of photosynthesis, green plants give off
 - a. hydrogen.
 - b. oxygen.
 - c. carbon dioxide.
 - d. helium.

SHORT ANSWER

20. Explain how Earth's early atmosphere differed from Earth's atmosphere today.
21. What is the shape of the planets' orbits?
22. What is Kepler's first law?
23. How did Newton's ideas about the orbits of the planets differ from Kepler's ideas?
24. List three features of Earth that allow it to sustain life.
25. Describe how a planet might form.
26. How did differentiation help to form solid Earth?

CRITICAL THINKING

- 27. Applying Ideas** Suppose astronomers discover that exoplanets orbiting stars similar to Earth's sun have similar compositions to the planets in Earth's solar system. What can the astronomers hypothesize about the formation of those solar systems?
- 28. Identifying Trends** If you know the distance from the sun to a planet, what other information can you determine about the orbit of the planet? Explain your answer.
- 29. Making Inferences** How would the layers of Earth be different if the planet had never been hotter than it is today?

CONCEPT MAPPING

- 30.** Use the following terms to create a concept map: *solar system, planet, protoplanet, planetesimal, differentiation, core, mantle, crust, geocentric, heliocentric, Aristotle, Ptolemy, Copernicus, ellipse, Earth, terrestrial planet, outer planet, Jupiter, Saturn, gas giant, Kuiper Belt, solar nebula, and inner planet.*

MATH SKILLS

Math Skills

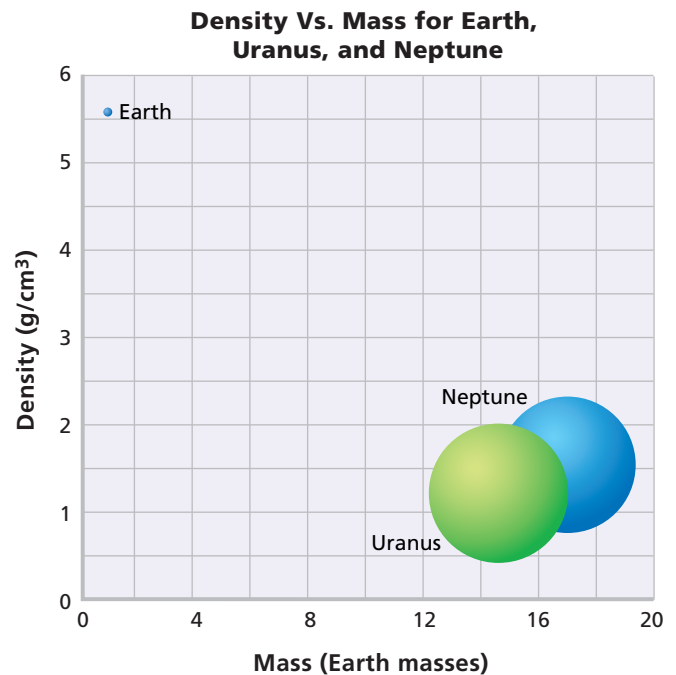
- 31. Making Calculations** Mercury has a period of rotation equal to 58.67 Earth days. Mercury's period of revolution is equal to 88 Earth days. How many times does Mercury rotate during one revolution around the sun?
- 32. Applying Quantities** Uranus's orbital period is 84 years. What is its distance from the sun in astronomical units?
- 33. Making Calculations** Venus's orbital period is 225 days. Calculate your age in Venus years.

WRITING SKILLS

- 34. Creative Writing** Imagine that you are the first astronaut to land on Mars. In a short essay, describe what you hope and expect to find.
- 35. Communicating Main Ideas** Create your own definition for *planet*. Then, write an explanation for why Pluto is or is not a planet.

INTERPRETING GRAPHICS

The graph below shows density in relation to mass for Earth, Uranus, and Neptune. Mass is given in Earth masses. The mass of Earth is equal to 1. Use the graph to answer the questions that follow.



- 36.** Which planet is denser, Uranus or Neptune? Explain your answer.
- 37.** Which planet has the smallest mass?
- 38.** How can Earth be the densest of the three planets even though Uranus and Neptune have so much more mass than Earth does?

Understanding Concepts

Directions (1–5): For each question, write on a separate sheet of paper the letter of the correct answer.

- Small bodies that join to form protoplanets in the early stages of the development of the solar system are
 - planets.
 - solar nebulas.
 - plantesimals.
 - gas giants.
- Scientists hypothesize that Earth's first oceans were made of fresh water. How did oceans obtain fresh water?
 - Water vapor in the early atmosphere cooled and fell to Earth as rain.
 - Frozen comets that fell to Earth melted as they traveled through the atmosphere.
 - As soon as icecaps formed, they melted because Earth was still very hot.
 - Early terrestrial organisms exhaled water vapor, which condensed to form fresh water.
- The original atmosphere of Earth consisted of
 - nitrogen and oxygen gases.
 - helium and hydrogen gases.
 - ozone and ammonia gases.
 - oxygen and carbon dioxide gases.
- Scientists think that the core of Earth is made of molten
 - iron and nickel.
 - nickel and magnesium.
 - silicon and nickel.
 - iron and silicon.
- Scientists estimate that the sun originated as a solar nebula and began to produce its own energy through nuclear fusion approximately how many years ago?
 - 50 million years
 - 500 million years
 - 1 billion years
 - 5 billion years

Directions (6–7): For each question, write a short response.

- What four planets make up the group known as the inner planets?
- The Great Red Spot is found on what planet?

Reading Skills

Directions (8–10): Read the passage below. Then, answer the questions.

Movement of the Planets

Imagine that it is the year 200 BCE and that you are an apprentice to a famous Greek astronomer. After many years of observing the sky, the astronomer knows all of the constellations as well as he knows the back of his hand. He shows you how all the stars move together—how the whole sky spins slowly as the night goes on. He also shows you that among the thousands of stars in the sky, some of the brighter ones slowly change their position in relation to the other stars. The astronomer names these stars *planetai*, the Greek word that means “wanderers.”

Building on the observations of the ancient Greeks, we now know that the planetai are actually planets, not wandering stars. Because of their proximity to Earth and their orbits around the sun, the planets appear to move relative to the stars.

- According to the passage, which of the following statements is not true?
 - It is possible to determine planets in the night sky by the way they move relative to the other stars.
 - The word *planetai* means “wanderers” in the Greek language.
 - Some of the earliest astronomers to detect the presence of planets were Roman.
 - Ancient Greeks were studying astronomy more than 2,200 years ago.
- What can you infer from the passage about the ancient Greek astronomers?
 - They were patient and observant.
 - They knew much more about astronomy than we do today.
 - They spent all their time counting the number of stars in the sky.
 - They invented astronomy and were the first people to observe the skies.
- What did the Greek astronomers note about the movement of stars and constellations?

