Section 1

Observing the Solar System

Reading Preview

Key Concepts

- What are the geocentric and heliocentric systems?
- How did Copernicus, Galileo, and Kepler contribute to our knowledge of the solar system?
- What objects make up the solar system?

Key Terms

- geocentric • heliocentric
- ellipse • moon

Target Reading Skill

Previewing Visuals Preview Figure 2 and Figure 3. Then write two questions that you have about the diagrams in a graphic organizer. As you read, answer your questions.

Models of the Universe

Q. What is a geocentric model?
A.
Q.

Lab zone Discover Activity

What Is at the Center?

1. Stand about 2 meters from a partner who is holding a flashlight. Have your partner shine the flashlight in your direction. Tell your partner not to move the flashlight.
2. Continue facing your partner, but move sideways in a circle, staying about 2 meters away from your partner.
3. Record your observations about your ability to see the light.
4. Repeat the activity, but this time remain stationary and continually face one direction. Have your partner continue to hold the flashlight toward you and move sideways around you, remaining about 2 meters from you.
5. Record your observations about your ability to see the light.

Think It Over

Drawing Conclusions Compare your two sets of observations. If you represent Earth and your partner represents the sun, is it possible, just from your observations, to tell whether Earth or the sun is in the center of the solar system?

Have you ever gazed up at the sky on a starry night? If you watch for several hours, the stars seem to move across the sky. The sky seems to be rotating right over your head. In fact, from the Northern Hemisphere, the sky appears to rotate completely around the North Star once every 24 hours.

Now think about what you see every day. During the day, the sun appears to move across the sky. From here on Earth, it seems as if Earth is stationary and that the sun, moon, and stars are moving around Earth. But is the sky really moving above you? Centuries ago, before there were space shuttles or even telescopes, there was no easy way to find out.

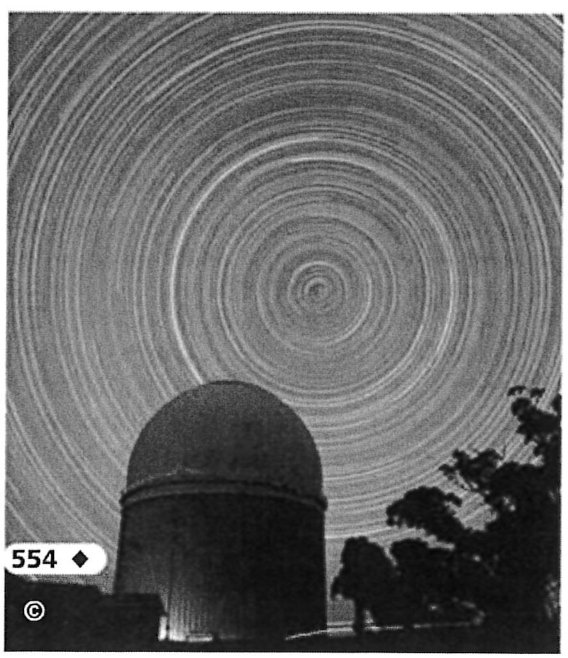


FIGURE 1
Star Trails
This photo was made by exposing the camera film for several hours. Each star appears as part of a circle, and all the stars seem to revolve around the North Star.

Earth at the Center

When the ancient Greeks watched the stars move across the sky, they noticed that the patterns of the stars didn't change. Although the stars seemed to move, they stayed in the same position relative to one another. These patterns of stars, called constellations, kept the same shapes from night to night and from year to year.

Greek Observations As the Greeks observed the sky, they noticed something surprising. Several points of light seemed to wander slowly among the stars. The Greeks called these objects *planets,* from the Greek word meaning "wanderers." The Greeks made careful observations of the motions of the planets that they could see. You know these planets by the names the ancient Romans later gave them: Mercury, Venus, Mars, Jupiter, and Saturn.

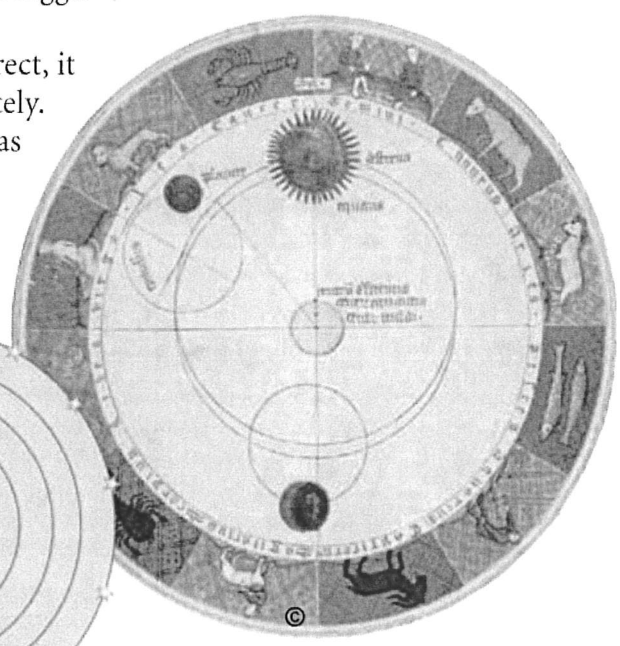
Most early Greek astronomers believed the universe to be perfect, with Earth at the center. The Greeks thought that Earth is inside a rotating dome they called the celestial sphere. Since *geo* is the Greek word for "Earth," an Earth-centered model is known as a geocentric (jee oh SEN trik) system. **In a geocentric system, Earth is at the center of the revolving planets and stars.**

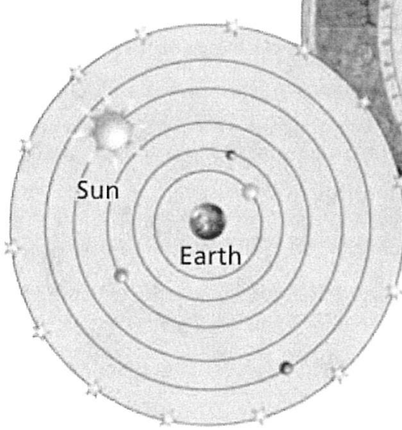
Ptolemy's Model About A.D. 140, the Greek astronomer Ptolemy (TAHL uh mee) further developed the geocentric model. Like the earlier Greeks, Ptolemy thought that Earth is at the center of a system of planets and stars. In Ptolemy's model, however, the planets move on small circles that move on bigger circles.

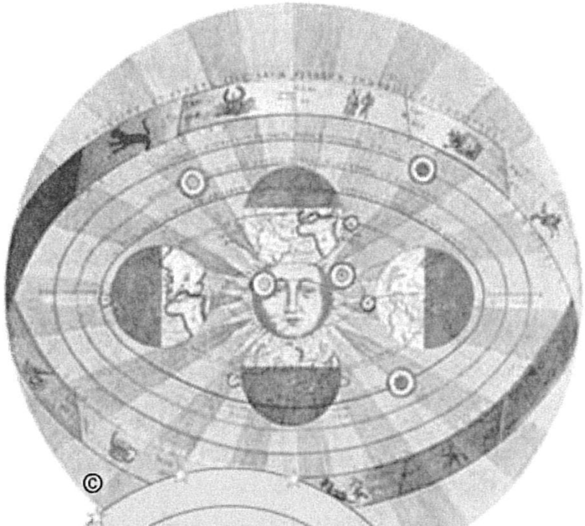
Even though Ptolemy's geocentric model was incorrect, it explained the motions observed in the sky fairly accurately. As a result, the geocentric model of the universe was widely accepted for nearly 1,500 years after Ptolemy.

Reading Checkpoint What is a geocentric system?

FIGURE 2
Geocentric System
In a geocentric system, the planets and stars are thought to revolve around a stationary Earth. In the 1500s, an astronomy book published the illustration of Ptolemy's geocentric system shown below.
Interpreting Diagrams *Where is Earth located in each illustration?*







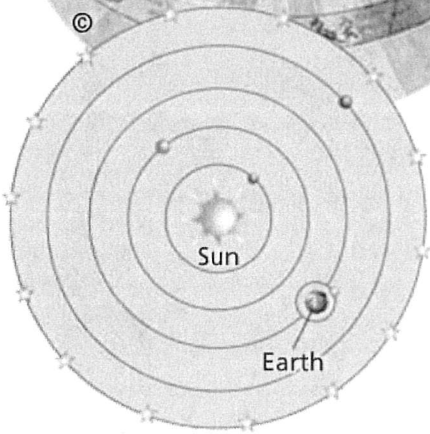


FIGURE 3
Heliocentric System
In a heliocentric system, Earth and the other planets revolve around the sun. The illustration by Andreas Cellarius (top) was made in the 1660s.
Interpreting Diagrams *In a heliocentric model, what revolves around Earth?*

Sun at the Center

Not everybody believed in the geocentric system. An ancient Greek scientist developed another explanation for the motion of the planets. This sun-centered model is called a **heliocentric** (hee lee oh SEN trik) system. *Helios* is Greek for "sun." **In a heliocentric system, Earth and the other planets revolve around the sun.** This model was not well received in ancient times, however, because people could not accept that Earth is not at the center of the universe.

The Copernican Revolution In 1543, the Polish astronomer Nicolaus Copernicus further developed the heliocentric model. **Copernicus was able to work out the arrangement of the known planets and how they move around the sun.** Copernicus's theory would eventually revolutionize the science of astronomy. But at first, many people were unwilling to accept his theory. They needed more evidence to be convinced.

In the 1500s and early 1600s, most people still believed in the geocentric model. However, evidence collected by the Italian scientist Galileo Galilei gradually convinced others that the heliocentric model was correct.

Galileo's Evidence **Galileo used the newly invented telescope to make discoveries that supported the heliocentric model.** For example, in 1610, Galileo used a telescope to discover four moons revolving around Jupiter. The motion of these moons proved that not every body in space revolves around Earth.

Nicolaus Copernicus
1473–1543

Galileo Galilei
1564–1642

▼ A reconstruction of Galileo's telescope

FIGURE 4
Major Figures in the History of Astronomy

Galileo's observations of Venus also supported the heliocentric system. Galileo knew that Venus is always seen near the sun. He discovered that Venus goes through a series of phases similar to those of Earth's moon. But Venus would not have a full set of phases if it circled around Earth. Therefore, Galileo reasoned, the geocentric model must be incorrect.

Tycho Brahe's Observations Copernicus correctly placed the sun at the center of the planets. But he incorrectly assumed that the planets travel in orbits that are perfect circles. Copernicus had based his ideas on observations made by the ancient Greeks.

In the late 1500s, the Danish astronomer Tycho Brahe (TEE koh BRAH uh) and his assistants made much more accurate observations. For more than 20 years, they carefully observed and recorded the positions of the planets. Surprisingly, these observations were made without using a telescope. Telescopes had not yet been invented!

Kepler's Calculations Tycho Brahe died in 1601. His assistant, Johannes Kepler, went to work analyzing the observations. Kepler began by trying to figure out the shape of Mars's orbit. At first, he assumed that the orbit was circular. But his calculations did not fit the observations. Kepler eventually found that Mars's orbit was a slightly flattened circle, or ellipse. An **ellipse** is an oval shape, which may be elongated or nearly circular.

After years of detailed calculations, Kepler reached a remarkable conclusion about the motion of the planets. **Kepler found that the orbit of each planet is an ellipse.** Kepler had used the evidence gathered by Tycho Brahe to disprove the long-held belief that the planets move in perfect circles.

Reading Checkpoint — **What is an ellipse?**

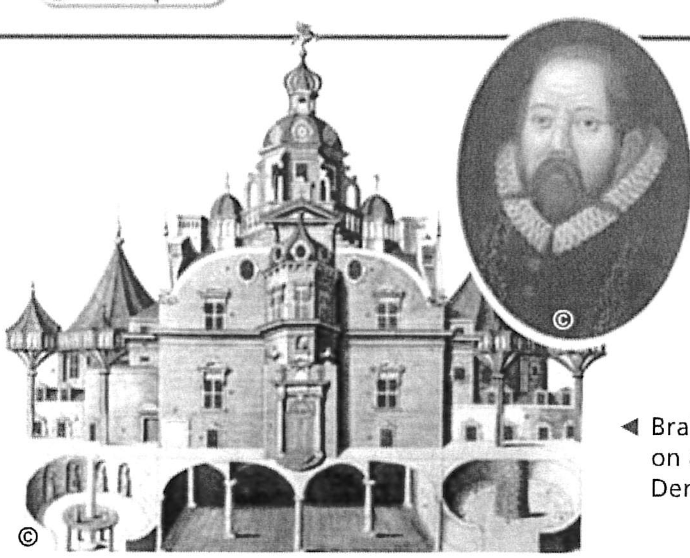
Lab zone Try This Activity

A Loopy Ellipse

You can draw an ellipse.

1. Carefully stick two pushpins about 10 cm apart through a sheet of white paper on top of corrugated cardboard. One pushpin represents the sun.
2. Tie the ends of a 30-cm piece of string together. Place the string around the pushpins.
3. Keeping the string tight, move a pencil around inside the string.
4. Now place the pushpins 5 cm apart. Repeat Step 3.

Predicting How does changing the distance between the pushpins affect the ellipse's shape? What shape would you draw if you used only one pushpin? Is the "sun" at the center of the ellipse?



Tycho Brahe
1546–1601

Johannes Kepler
1571–1630

Brahe's observatory on an island between Denmark and Sweden

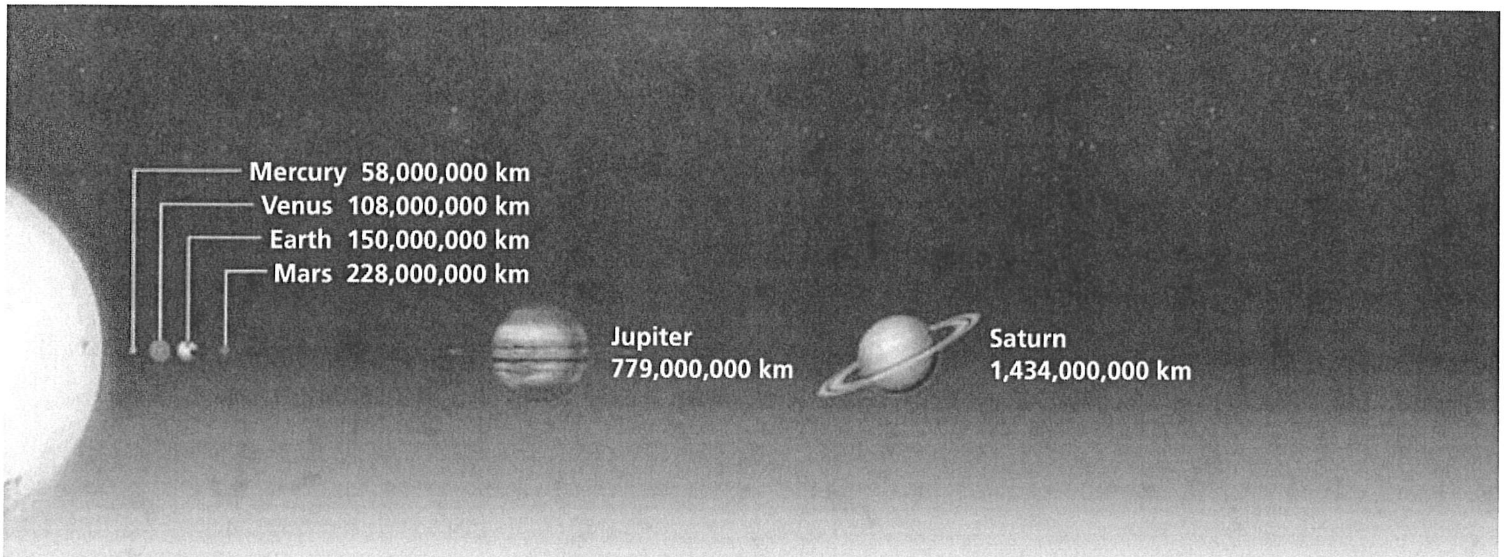


FIGURE 5
The Sun and Planets
This illustration shows the average distances of the planets from the sun. The solar system also includes smaller bodies, such as Pluto. These distances are drawn to scale, but the sizes of the planets are not drawn to the same scale.
Observing *Which planet is closest to the sun?*

Modern Discoveries

Today, people accept the idea that Earth and the other planets revolve around the sun. Since Galileo's time, our knowledge of the solar system has increased dramatically. Galileo knew the same planets that the ancient Greeks had known—Mercury, Venus, Earth, Mars, Jupiter, and Saturn. Since Galileo's time, astronomers have discovered two more planets—Uranus and Neptune—as well as Pluto, which is no longer classified as a planet. Astronomers have also identified many other objects in the solar system, such as comets and asteroids. **Today we know that the solar system consists of the sun, the planets and their moons, and several kinds of smaller objects that revolve around the sun.** A **moon** is a natural satellite that revolves around a planet.

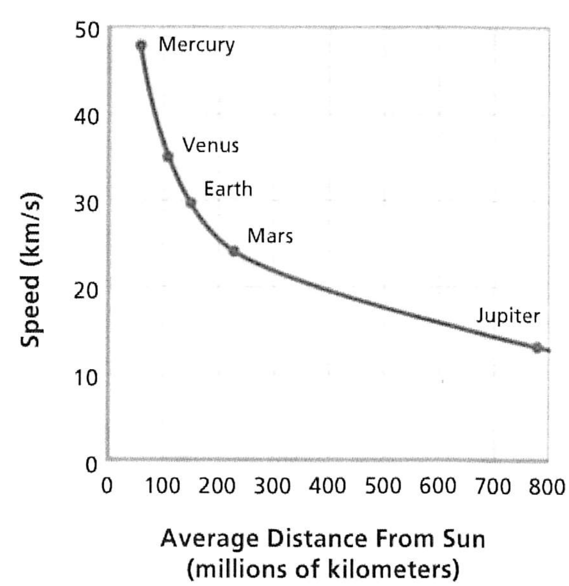
Math Analyzing Data

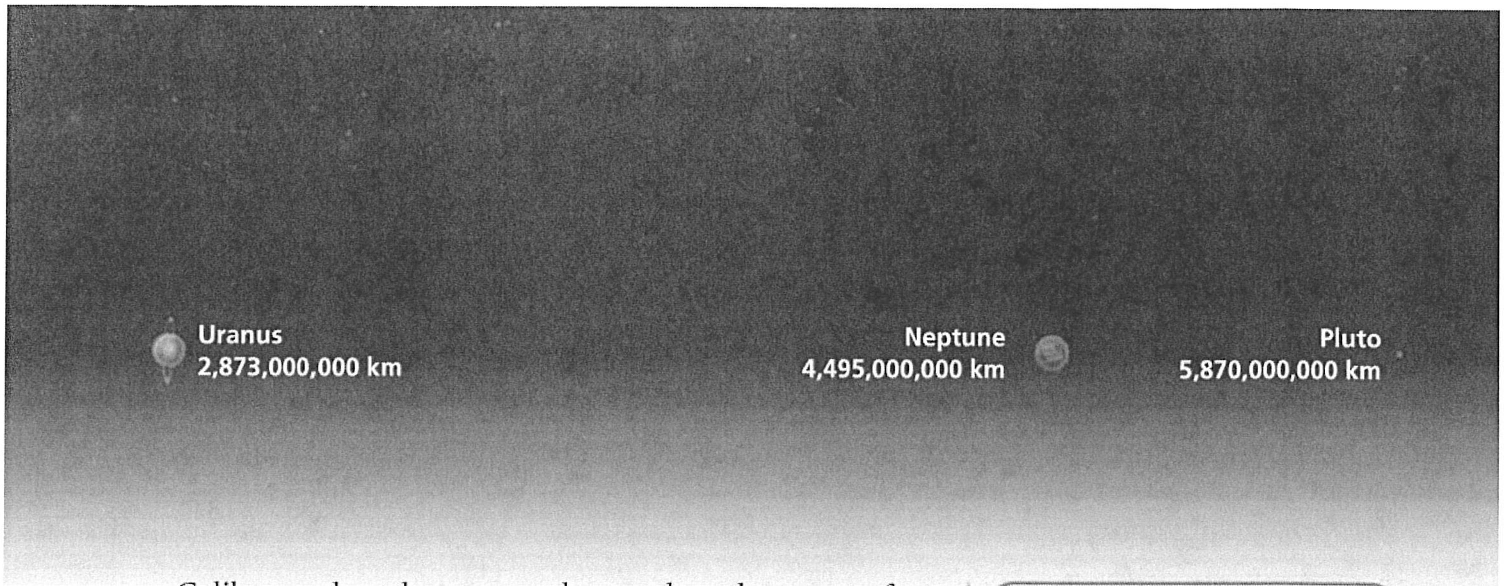
Planet Speed Versus Distance

Johannes Kepler discovered a relationship between the speed of a planet and its distance from the sun. Use the graph to help discover what Kepler learned.

1. **Reading Graphs** According to the graph, what is Earth's average speed?
2. **Interpreting Data** Which is closer to the sun, Mercury or Mars? Which moves faster?
3. **Drawing Conclusions** What is the general relationship between a planet's speed and its average distance from the sun?
4. **Predicting** The planet Uranus is about 2,900 million km from the sun. Predict whether its speed is greater or less than Jupiter's speed. Explain your answer.

Speed of Planets





Galileo used a telescope to observe the solar system from Earth's surface. Astronomers today still use telescopes located on Earth, but they have also placed telescopes in space to gain a better view of the universe beyond Earth. Scientists have also sent astronauts to the moon and launched numerous space probes to explore the far reaches of the solar system. Our understanding of the solar system continues to grow every day. Who knows what new discoveries will be made in your lifetime!

Reading Checkpoint Which six planets were known to the ancient Greeks?

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Section 1 Assessment

Vocabulary Skill Greek Word Origins How does knowing Greek word origins help you remember the terms *geocentric* and *heliocentric?*

Reviewing Key Concepts

1. a. **Explaining** What are the geocentric and heliocentric systems?
   b. **Comparing and Contrasting** How was Copernicus's model of the universe different from Ptolemy's model?
   c. **Drawing Conclusions** What discoveries by Galileo support the heliocentric model?
   d. **Applying Concepts** People often say the sun rises in the east, crosses the sky, and sets in the west. Is this literally true? Explain.
2. a. **Interpreting Data** How did Kepler use Tycho Brahe's data?
   b. **Describing** What did Kepler discover about the orbits of the planets?
   c. **Inferring** How did Tycho Brahe and Kepler employ the scientific method?
3. a. **Describing** What objects make up the solar system?
   b. **Listing** What are the planets, in order of increasing distance from the sun?
   c. **Interpreting Diagrams** Use Figure 5 to find the planet with the closest orbit to Earth.

Writing in Science

Dialogue Write an imaginary conversation between Ptolemy and Galileo about the merits of the geocentric and heliocentric systems. Which system would each scientist favor? What evidence could each offer to support his view? Do you think that one scientist could convince the other to change his mind? Use quotation marks around the comments of each scientist.

Section 3

The Inner Planets

Reading Preview

Key Concepts

- What characteristics do the inner planets have in common?
- What are the main characteristics that distinguish each of the inner planets?

Key Terms

- terrestrial planets
- greenhouse effect

Target Reading Skill

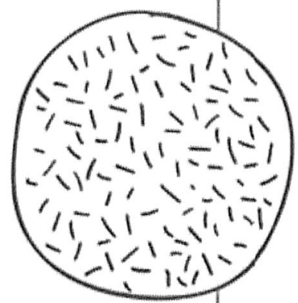
Using Prior Knowledge Look at the section headings and visuals to see what this section is about. Then write what you know about the inner planets in a graphic organizer like the one below. As you read, write what you learn.

What You Know
1. Most of Earth is covered with water. 2.

What You Learned
1. 2.

Lab zone Discover Activity

How Does Mars Look From Earth?



1. Work in pairs. On a sheet of paper, draw a circle 20 cm across to represent Mars. Draw about 100 small lines, each about 1 cm long, at random places inside the circle.
2. Have your partner look at your drawing of Mars from the other side of the room. Your partner should draw what he or she sees.
3. Compare your original drawing with what your partner drew. Then look at your own drawing from across the room.

Think It Over

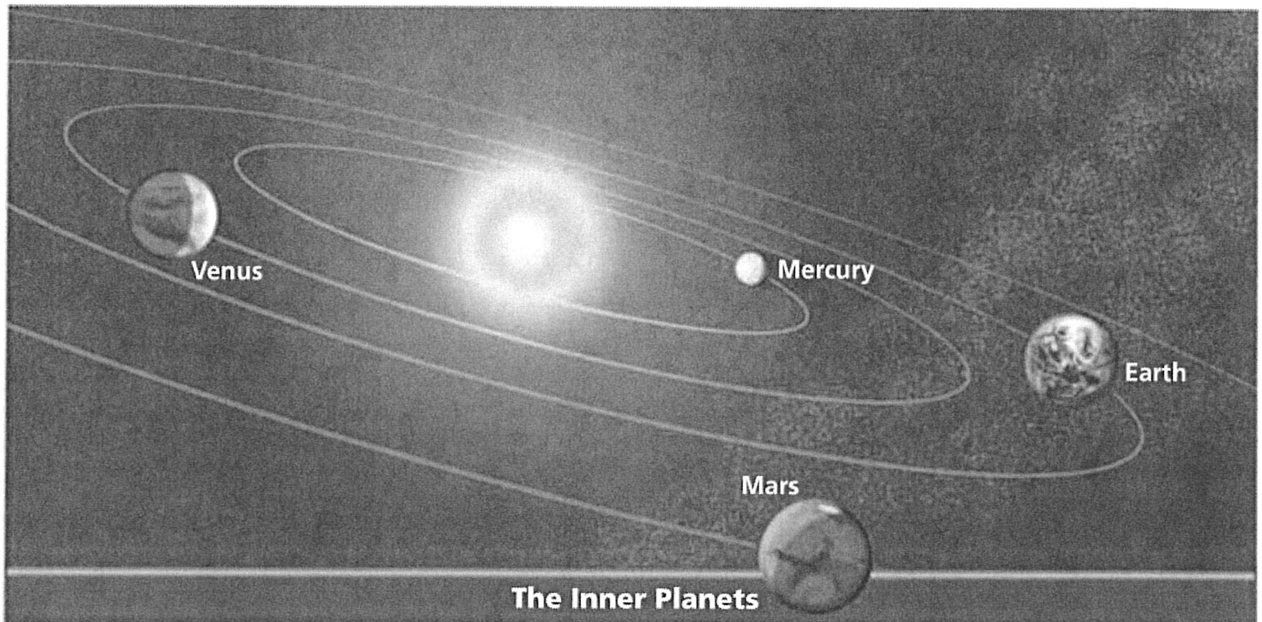
Observing Did your partner draw any connecting lines that were not actually on your drawing? What can you conclude about the accuracy of descriptions of other planets based on observations from Earth?

Where could you find a planet whose atmosphere has almost entirely leaked away into space? How about a planet whose surface is hot enough to melt lead? And how about a planet with volcanoes higher than any on Earth? Finally, where could you find a planet with oceans of water brimming with fish and other life? These are descriptions of the four planets closest to the sun, known as the inner planets.

Earth and the three other inner planets—Mercury, Venus, and Mars—are more similar to each other than they are to the five outer planets. **The four inner planets are small and dense and have rocky surfaces.** The inner planets are often called the **terrestrial planets,** from the Latin word *terra,* which means "Earth." Figure 10 summarizes data about the inner planets.

Earth

As you can see in Figure 11, Earth has three main layers—a crust, a mantle, and a core. The crust includes the solid, rocky surface. Under the crust is the mantle, a layer of hot molten rock. When volcanoes erupt, this hot material rises to the surface. Earth has a dense core made of mainly iron and nickel. The outer core is liquid, but the inner core is solid.



Planet	Diameter (kilometers)	Period of Rotation (Earth days)	Average Distance From Sun (kilometers)	Period of Revolution (Earth years)	Number of Moons
Mercury	4,879	59	58,000,000	0.24	0
Venus	12,104	243	108,000,000	0.62	0
Earth	12,756	1	150,000,000	1	1
Mars	6,794	1.03	228,000,000	1.9	2

FIGURE 10
The inner planets take up only a small part of the solar system. Note that sizes and distances are not drawn to scale.

Water **Earth is unique in our solar system in having liquid water at its surface.** In fact, most of Earth's surface, about 70 percent, is covered with water. Perhaps our planet should be called "Water" instead of "Earth"! Earth has a suitable temperature range for water to exist as a liquid, gas, or solid. Water is also important in shaping Earth's surface, wearing it down and changing its appearance over time.

Atmosphere Earth has enough gravity to hold on to most gases. These gases make up Earth's atmosphere, which extends more than 100 kilometers above its surface. Other planets in the solar system have atmospheres too, but only Earth has an atmosphere that is rich in oxygen. The oxygen you need to live makes up about 20 percent of Earth's atmosphere. Nearly all the rest is nitrogen, with small amounts of other gases such as argon and carbon dioxide. The atmosphere also includes varying amounts of water in the form of a gas. Water in a gaseous form is called water vapor.

Reading Checkpoint What two gases make up most of Earth's atmosphere?

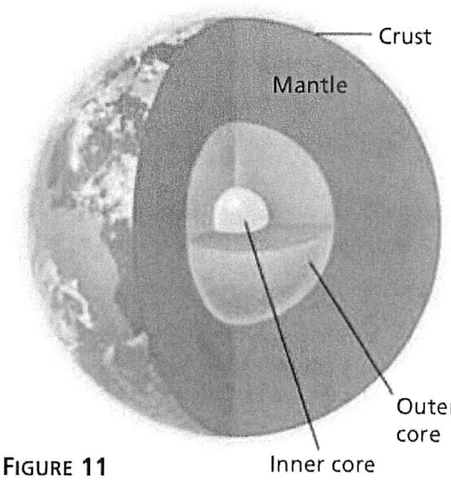
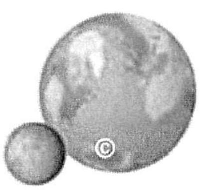


FIGURE 11
Earth's Layers
Earth has a solid, rocky surface.
Interpreting Diagrams *What are Earth's three main layers?*

FIGURE 12
Mercury
This image of Mercury was produced by combining a series of smaller images made by the *Mariner 10* space probe.
Interpreting Photographs *How is Mercury's surface different from Earth's?*



Size of Mercury compared to Earth

Mercury

Mercury is the smallest terrestrial planet and the planet closest to the sun. Mercury is not much larger than Earth's moon and has no moons of its own. The interior of Mercury is probably made up mainly of the dense metal iron.

Exploring Mercury Because Mercury is so close to the sun, it is hard to see from Earth. Much of what astronomers know about Mercury's surface came from a single probe, *Mariner 10*. It flew by Mercury three times in 1974 and 1975. Two new missions to Mercury are planned. The first of these, called *MESSENGER*, is scheduled to go into orbit around Mercury in 2009.

Mariner 10's photographs show that Mercury has many flat plains and craters on its surface. The large number of craters shows that Mercury's surface has changed little for billions of years. Many of Mercury's craters have been named for artists, writers, and musicians, such as the composers Bach and Mozart.

Mercury's Atmosphere Mercury has virtually no atmosphere. Mercury's high daytime temperatures cause gas particles to move very fast. Because Mercury's mass is small, its gravity is weak. Fast-moving gas particles can easily escape into space. However, astronomers have detected small amounts of sodium and other gases around Mercury.

Mercury is a planet of extremes, with a greater temperature range than any other planet in the solar system. It is so close to the sun that during the day, the side facing the sun reaches temperatures of 430°C. Because Mercury has almost no atmosphere, at night its heat escapes into space. Then its temperature drops below −170°C.

Venus

Venus is so similar in size and mass to Earth that it is sometimes called "Earth's twin." **Venus's density and internal structure are similar to Earth's. But, in other ways, Venus and Earth are very different.**

Venus takes about 7.5 Earth months to revolve around the sun. It takes about 8 months for Venus to rotate once on its axis. Thus, Venus rotates so slowly that its day is longer than its year! Oddly, Venus rotates from east to west, the opposite direction from most other planets and moons. Astronomers hypothesize that a large object struck Venus long ago, causing the planet to change its direction of rotation.

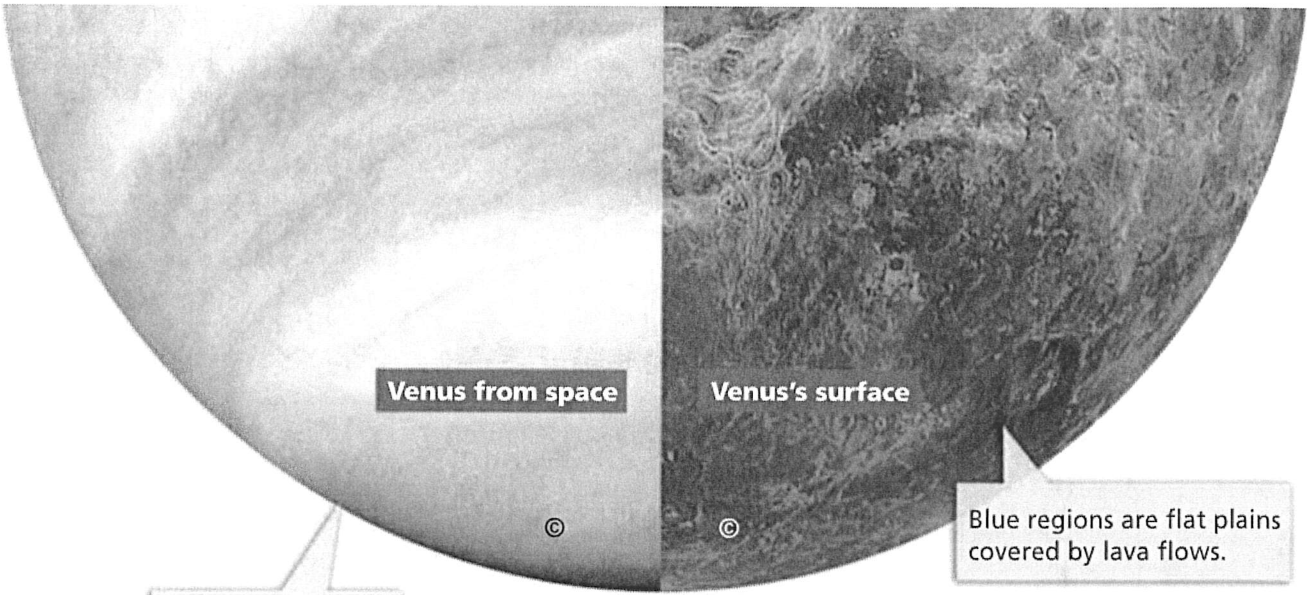


FIGURE 13
Venus
An image made with a camera (left) shows Venus's thick atmosphere. A radar image (right) penetrates Venus's clouds to reveal the surface. Both images are false color.

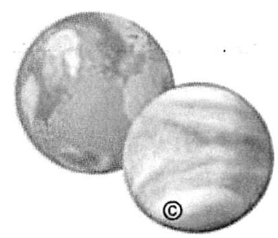
Venus's Atmosphere Venus's atmosphere is so thick that it is always cloudy there. From Earth or space, astronomers can see only a smooth cloud cover over Venus. The clouds are made mostly of droplets of sulfuric acid.

If you could stand on Venus's surface, you would quickly be crushed by the weight of its atmosphere. The pressure of Venus's atmosphere is 90 times greater than the pressure of Earth's atmosphere. You couldn't breathe on Venus because its atmosphere is mostly carbon dioxide.

Because Venus is closer to the sun than Earth is, it receives more solar energy than Earth does. Much of this radiation is reflected by Venus's atmosphere. However, some radiation reaches the surface and is later given off as heat. The carbon dioxide in Venus's atmosphere traps heat so well that Venus has the hottest surface of any planet. At 460°C, its average surface temperature is hot enough to melt lead. This trapping of heat by the atmosphere is called the **greenhouse effect.**

Exploring Venus Many space probes have visited Venus. The first probe to land on the surface and send back data, *Venera 7*, landed in 1970. The *Magellan* probe reached Venus in 1990, carrying radar instruments. Radar works through clouds, so *Magellan* was able to map nearly the entire surface. The *Magellan* data confirmed that Venus is covered with rock. Venus's surface has many volcanoes and broad plains formed by lava flows.

Reading Checkpoint **How is Venus's surface temperature affected by the greenhouse effect?**



Size of Venus compared to Earth

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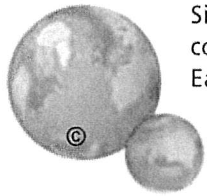


Size of Mars compared to Earth

Mars

Mars is called the "red planet." When you see it in the sky, it has a slightly reddish tinge. This reddish color is due to the breakdown of iron-rich rocks, which creates a rusty dust that covers much of Mars's surface.

Mars's Atmosphere The atmosphere of Mars is more than 95 percent carbon dioxide. It is similar in composition to Venus's atmosphere, but much thinner. You could walk around on Mars, but you would have to wear an airtight suit and carry your own oxygen, like a scuba diver. Mars has few clouds, and they are very thin compared to clouds on Earth. Mars's transparent atmosphere allows people on Earth to view its surface with a telescope. Temperatures on the surface range from $-140^{\circ}C$ to $20^{\circ}C$.

Water on Mars Images of Mars taken from space show a variety of features that look as if they were made by ancient streams, lakes, or floods. There are huge canyons and features that look like the remains of ancient coastlines. **Scientists think that a large amount of liquid water flowed on Mars's surface in the distant past.** Scientists infer that Mars must have been much warmer and had a thicker atmosphere at that time.

At present, liquid water cannot exist for long on Mars's surface. Mars's atmosphere is so thin that any liquid water would quickly turn into a gas. So where is Mars's water now? Some of it is located in the planet's two polar ice caps, which contain frozen water and carbon dioxide. A small amount also exists as water vapor in Mars's atmosphere. Some water vapor has probably escaped into space. But scientists think that a large amount of water may still be frozen underground.

Seasons on Mars Because Mars has a tilted axis, it has seasons just as Earth does. During the Martian winter, an ice cap grows larger as a layer of frozen carbon dioxide covers it. Because the northern and southern hemispheres have opposite seasons, one ice cap grows while the other one shrinks.

As the seasons change on the dusty surface of Mars, windstorms arise and blow the dust around. Since the dust is blown off some regions, these regions look darker.

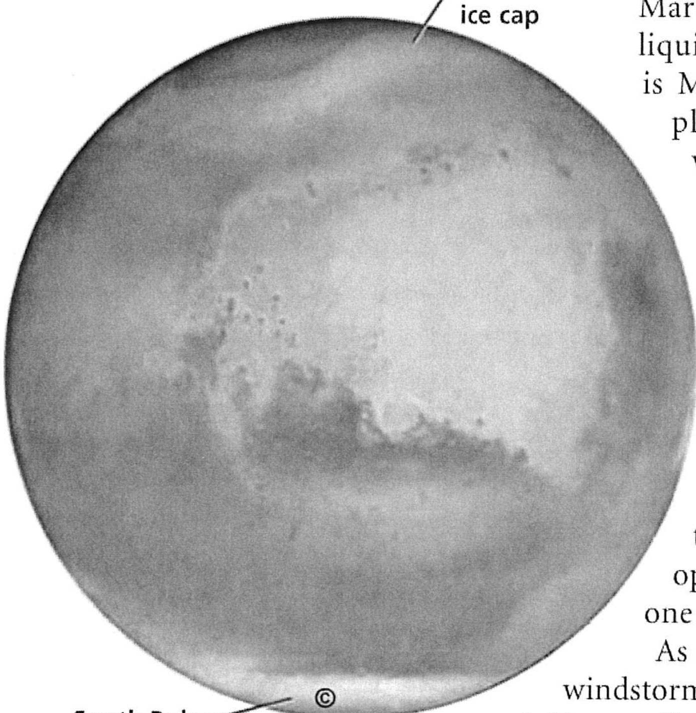


FIGURE 14
Mars
Because of its thin atmosphere and its distance from the sun, Mars is quite cold. Mars has ice caps at both poles. **Inferring** *Why is it easy to see Mars's surface from space?*

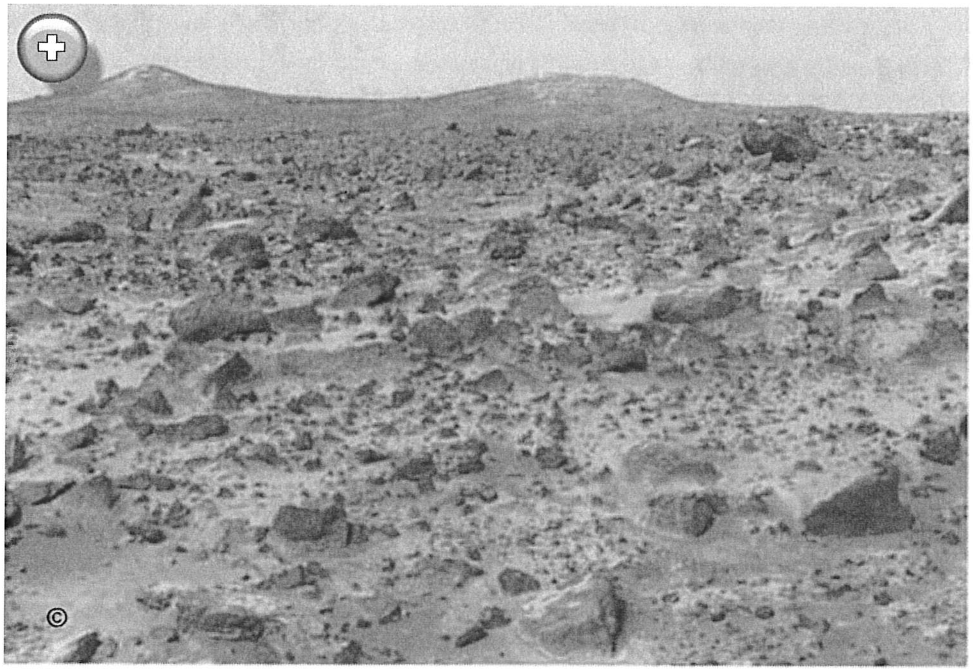


FIGURE 15
Mars's Surface
The surface of Mars is rugged and rocky.

Exploring Mars Many space probes have visited Mars. The first ones seemed to show that Mars is barren and covered with craters like the moon. Recently, two new probes landed on Mars's surface. NASA's *Spirit* and *Opportunity* rovers explored opposite sides of the planet. They examined a variety of rocks and soil samples. At both locations, the rovers found strong evidence that liquid water was once present.

Some regions of Mars have giant volcanoes. Astronomers see signs that lava flowed from the volcanoes in the past, but the volcanoes are no longer active. *Olympus Mons* on Mars is the largest volcano in the solar system.

Reading Checkpoint **What is the largest volcano in the solar system?**

Discovery Channel School

The Solar System

Video Preview
▶ Video Field Trip
Video Assessment

Section 3 Assessment

Target Reading Skill

Using Prior Knowledge Review your graphic organizer and revise it based on what you just learned in the section.

Reviewing Key Concepts

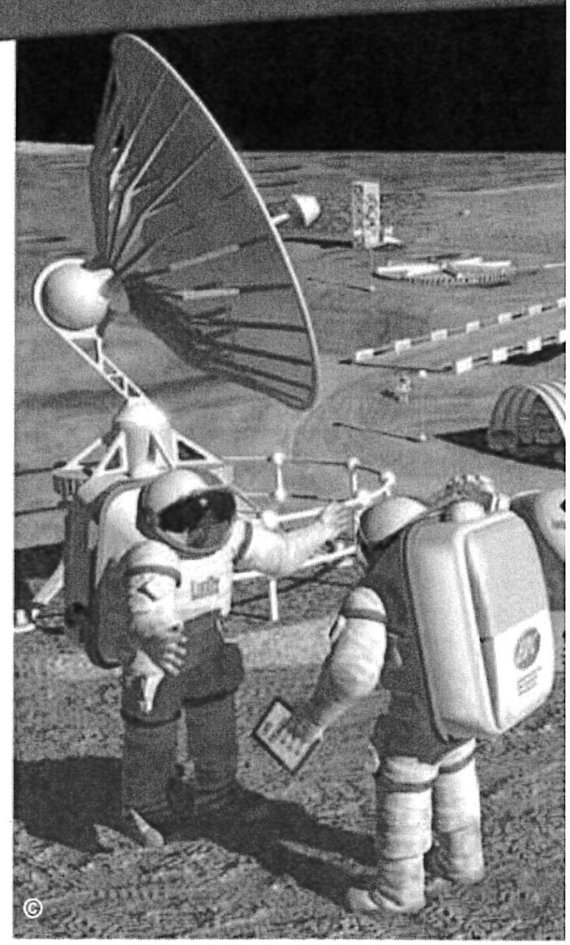
HINT
HINT
HINT
HINT

1. a. **Listing** List the four inner planets in order of size, from smallest to largest.
   b. **Comparing and Contrasting** How are the four inner planets similar to one another?
2. a. **Describing** Describe an important characteristic of each inner planet.
   b. **Comparing and Contrasting** Compare the atmospheres of the four inner planets.
   c. **Relating Cause and Effect** Venus is much farther from the sun than Mercury is. Yet average temperatures on Venus's surface are much higher than those on Mercury. Explain why. HINT

Writing in Science

Travel Brochure Select one of the inner planets other than Earth. Design a travel brochure for your selected planet, including basic facts and descriptions of places of interest. Also include a few sketches or photos to go along with your text.

Science and Society

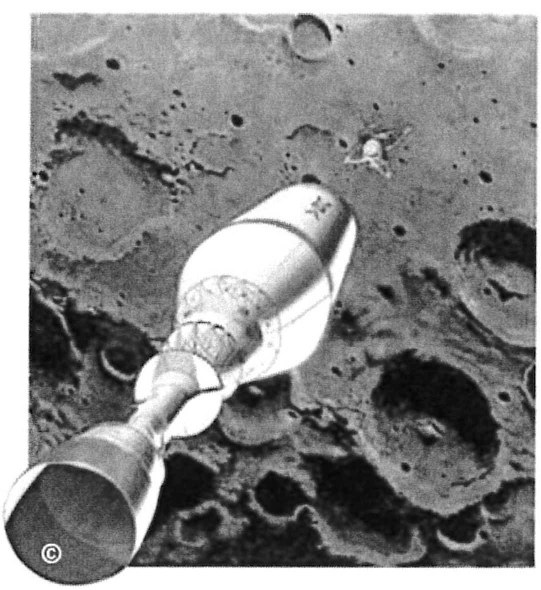


Space Exploration—Is It Worth the Cost?

Imagine that your spacecraft has just landed on the moon or on Mars. You've spent years planning for this moment. Canyons, craters, plains, and distant mountains stretch out before you. Perhaps a group of scientists has already begun construction of a permanent outpost. You check your spacesuit and prepare to step out onto the rocky surface.

Is such a trip likely? Would it be worthwhile? How much is space flight really worth to human society? Scientists and public officials have already started to debate such questions. Space exploration can help us learn more about the universe. But exploration can be risky and expensive. Sending people into space costs billions of dollars and risks the lives of astronauts. How can we balance the costs and benefits of space exploration?

▼ **Moon Landing**
A rocket is preparing to dock with a lander on the moon's surface in this imaginative artwork.



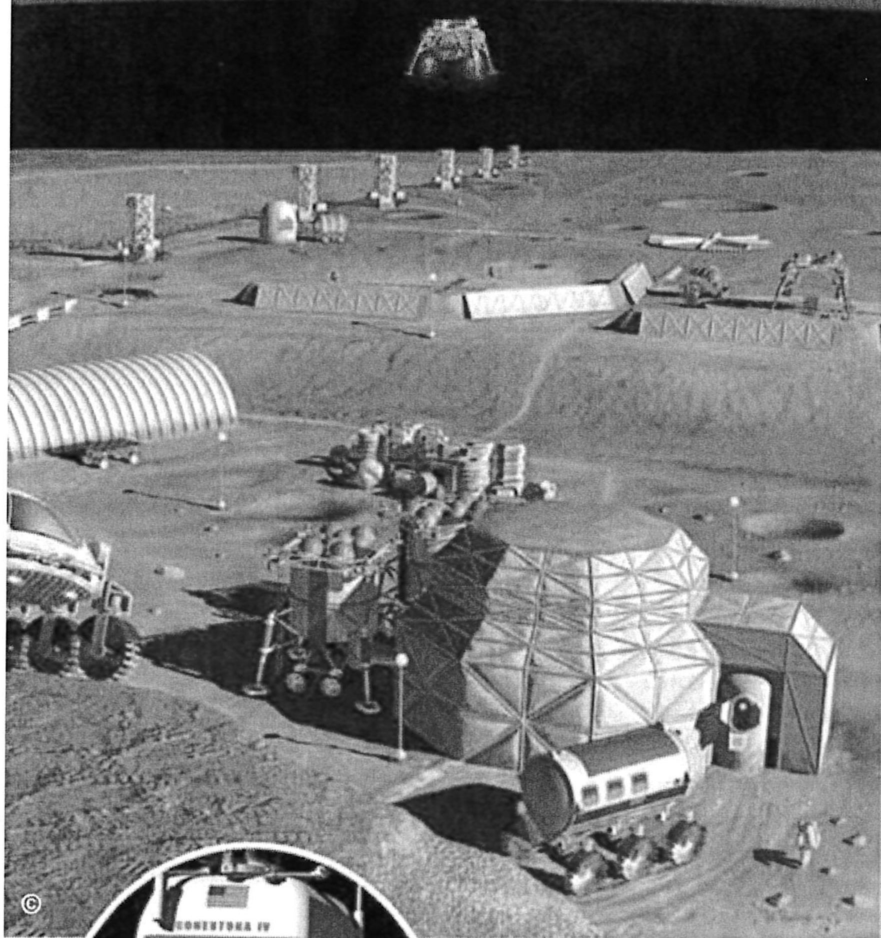
The Issues

Should Humans Travel Into Space?

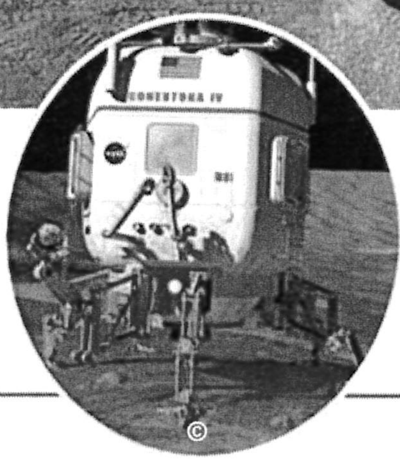
Many Americans think that Neil Armstrong's walk on the moon in 1969 was one of the great moments in history. Learning how to keep people alive in space has led to improvements in everyday life. Safer equipment for firefighters, easier ways to package frozen food, and effective heart monitors have all come from space program research.

What Are the Alternatives?

Space exploration can involve a project to establish a colony on the moon or Mars. It also can involve a more limited use of scientific instruments near Earth, such as the Hubble Space Telescope. Instead of sending people, we could send space probes like *Cassini* to other planets.



◀ **Lunar Outpost**
A mining operation on the moon is shown in this imaginative artwork. Such a facility may someday harvest oxygen from the moon's soil.



◀ **Lunar Module**
This artwork shows a futuristic vehicle that may one day be used to explore the moon and Mars. The vehicle serves as a combination lander, rover, and habitat for astronauts.

Is Human Space Exploration Worth the Cost?

Scientists who favor human travel into space say that only people can collect certain kinds of information. They argue that the technologies developed for human space exploration will have many applications on Earth. But no one knows if research in space really provides information more quickly than research that can be done on Earth. Many critics of human space exploration think that other needs are more important. One United States senator said, "Every time you put money into the space station, there is a dime that won't be available for our children's education or for medical research."

You Decide

1. **Identify the Problem**
   In your own words, list the various costs and benefits of space exploration.

2. **Analyze the Options**
   Make a chart of three different approaches to space exploration: sending humans to the moon or another planet, doing only Earth-based research, and one other option. What are the benefits and drawbacks of each of these approaches?

3. **Find a Solution**
   Imagine that you are a member of Congress who has to vote on a new budget. There is a fixed amount of money to spend, so you have to decide which needs are most important. Make a list of your top ten priorities. Explain your decisions.

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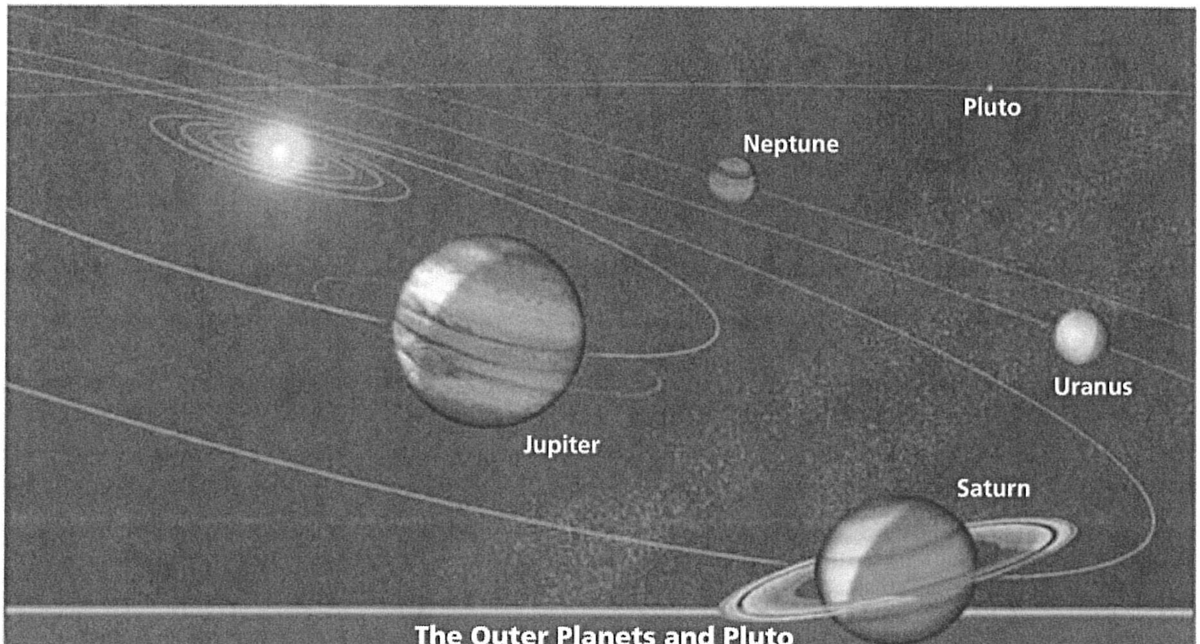

The Outer Planets and Pluto

Planet or Dwarf Planet	Size (kilometers)		Period of Rotation (Earth days)	Average Distance From Sun (AU)	Period of Revolution (Earth years)	Number of Moons
	Diameter	Radius				
Jupiter	143,000	71,490	0.41	5.2	12	63+
Saturn	120,500	60,270	0.45	9.6	29	47+
Uranus	51,120	25,560	0.72	19.2	84	27+
Neptune	49,530	24,760	0.67	30.0	164	13+
Pluto	2,390	1,200	6.4	39.2	248	3

FIGURE 16
The outer planets are much farther apart than the inner planets. Pluto is now considered a dwarf planet. Note that planet sizes and distances are not drawn to scale. **Observing** *Which outer planet has the most moons?*

Gas Giants and Pluto

Jupiter and the other planets farthest from the sun are called the outer planets. **The four outer planets—Jupiter, Saturn, Uranus, and Neptune—are much larger and more massive than Earth, and they do not have solid surfaces.** Because these four planets are all so large, they are often called the **gas giants.** Figure 16 provides information about these planets. It also includes Pluto, which is now classified as a dwarf planet.

Like the sun, the gas giants are composed mainly of hydrogen and helium. Because they are so massive, the gas giants exert a much stronger gravitational force than the terrestrial planets. Gravity keeps the giant planets' gases from escaping, so they have thick atmospheres. Despite the name "gas giant," much of the hydrogen and helium is actually in liquid form because of the enormous pressure inside the planets. The outer layers of the gas giants are extremely cold because of their great distance from the sun. Temperatures increase greatly within the planets.

All the gas giants have many moons. In addition, each of the gas giants is surrounded by a set of rings. A **ring** is a thin disk of small particles of ice and rock.

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Size of Jupiter compared to Earth

Jupiter

Jupiter is the largest and most massive planet. Jupiter's enormous mass dwarfs the other planets. In fact, its mass is about $2\frac{1}{2}$ times that of all the other planets combined!

Jupiter's Atmosphere Like all of the gas giants, Jupiter has a thick atmosphere made up mainly of hydrogen and helium. An especially interesting feature of Jupiter's atmosphere is its Great Red Spot, a storm that is larger than Earth! The storm's swirling winds blow hundreds of kilometers per hour, similar to a hurricane. But hurricanes on Earth weaken quickly as they pass over land. On Jupiter, there is no land to weaken the huge storm. The Great Red Spot, which was first observed in the mid-1600s, shows no signs of going away soon.

Jupiter's Structure Astronomers think that Jupiter, like the other giant planets, probably has a dense core of rock and iron at its center. As shown in Figure 17, a thick mantle of liquid hydrogen and helium surrounds this core. Because of the crushing weight of Jupiter's atmosphere, the pressure at Jupiter's core is estimated to be about 30 million times greater than the pressure at Earth's surface.

Jupiter's Moons Recall that Galileo discovered Jupiter's four largest moons. These moons, which are highlighted in Figure 18, are named Io (EYE oh), Europa, Ganymede, and Callisto. All four are larger than Earth's own moon. However, they are very different from one another. Since Galileo's time, astronomers have discovered dozens of additional moons orbiting Jupiter. Many of these are small moons that have been found in the last few years thanks to improved technology.

Reading Checkpoint What is Jupiter's atmosphere composed of?

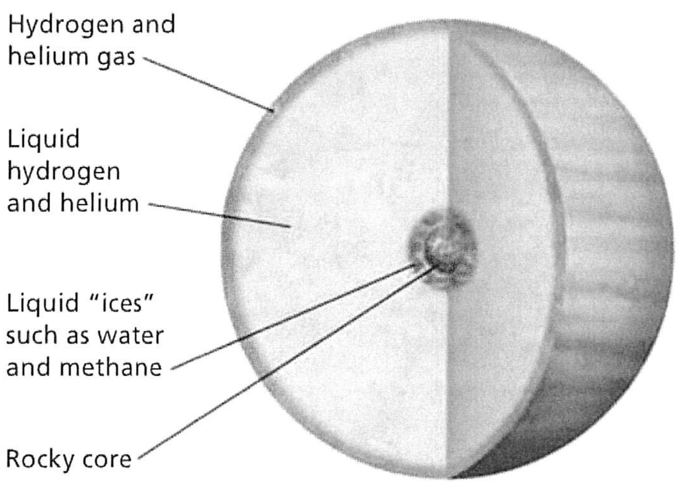


FIGURE 17
Jupiter's Structure
Jupiter is composed mainly of the elements hydrogen and helium. Although Jupiter is often called a "gas giant," much of it is actually liquid.
Comparing and Contrasting *How does the structure of Jupiter differ from that of a terrestrial planet?*

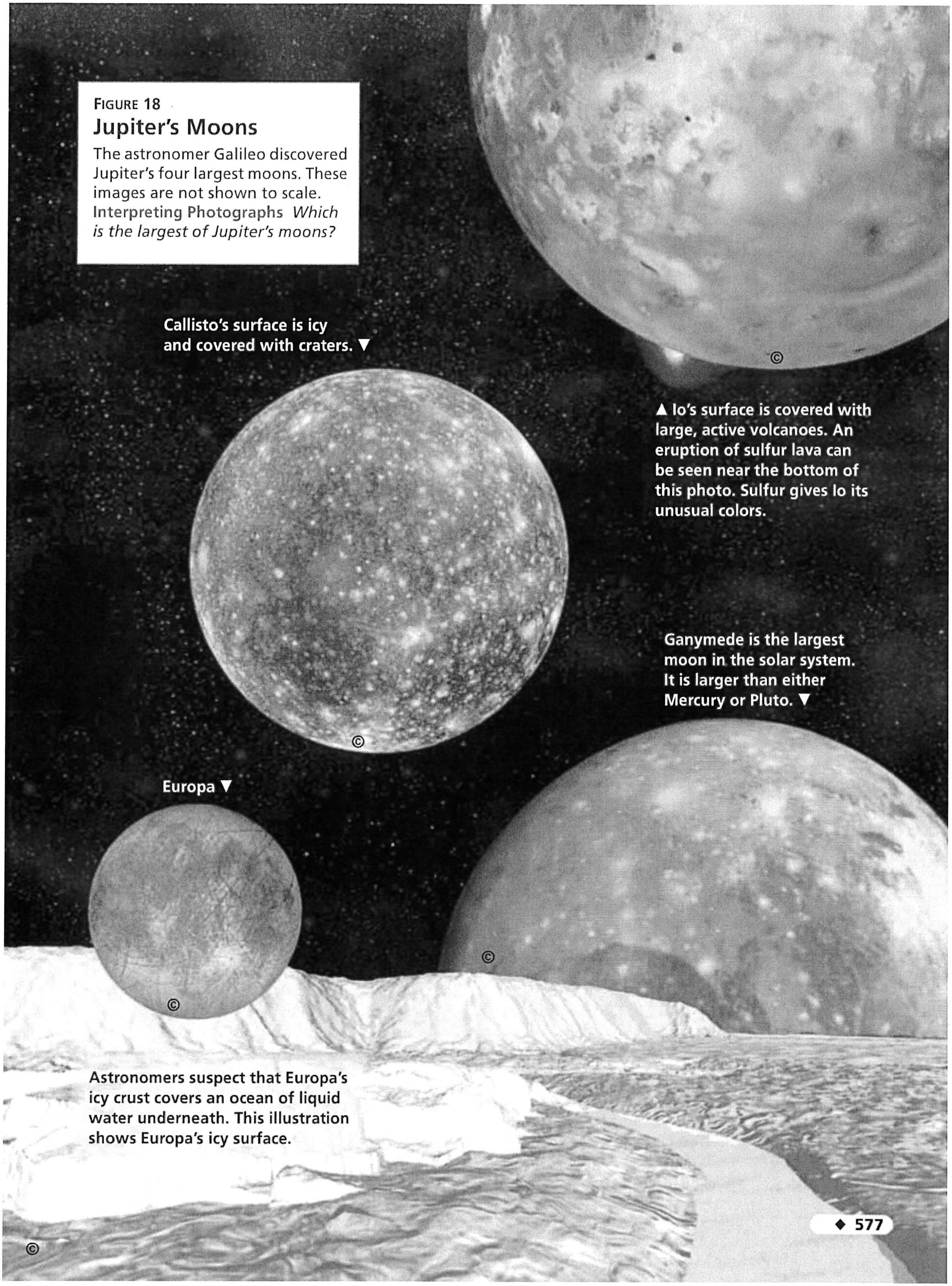


FIGURE 18
Jupiter's Moons
The astronomer Galileo discovered Jupiter's four largest moons. These images are not shown to scale.
Interpreting Photographs *Which is the largest of Jupiter's moons?*

▲ Io's surface is covered with large, active volcanoes. An eruption of sulfur lava can be seen near the bottom of this photo. Sulfur gives Io its unusual colors.

Callisto's surface is icy and covered with craters. ▼

Ganymede is the largest moon in the solar system. It is larger than either Mercury or Pluto. ▼

Europa ▼

Astronomers suspect that Europa's icy crust covers an ocean of liquid water underneath. This illustration shows Europa's icy surface.

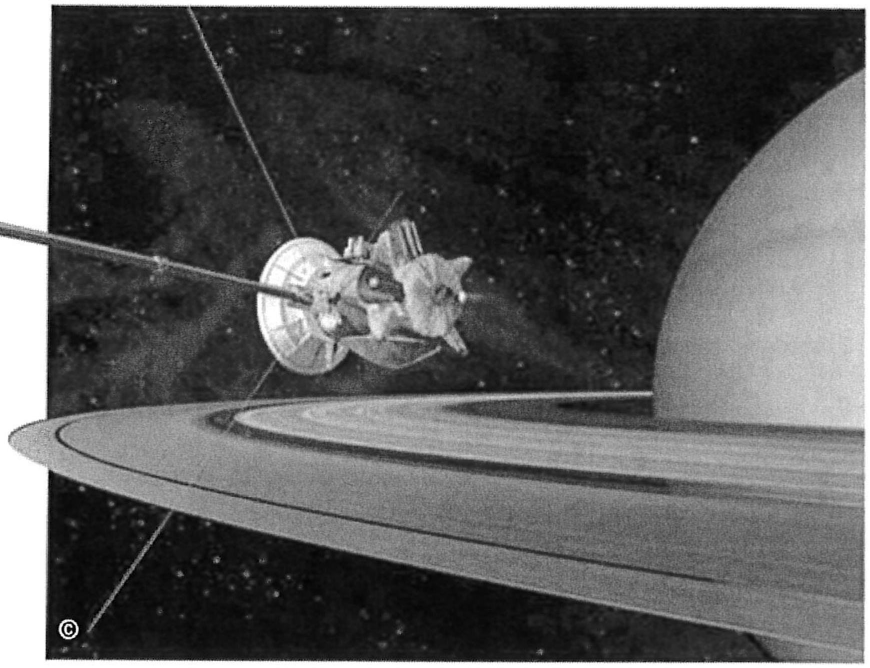
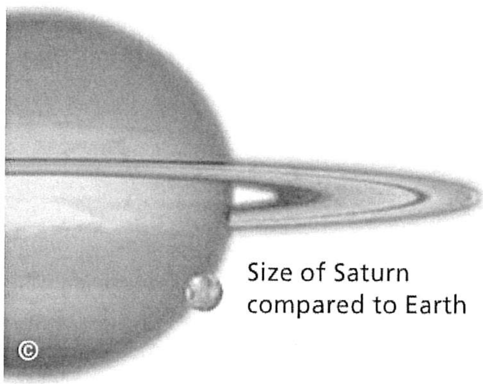


FIGURE 19
Exploring Saturn
The *Cassini* probe is exploring Saturn and its moons.
Observing *Why might it be hard to see Saturn's rings when their edges are facing Earth?*



Lab zone Skills Activity

Making Models

1. Use a plastic foam sphere 8 cm in diameter to represent Saturn.
2. Use an overhead transparency to represent Saturn's rings. Cut a circle 18 cm in diameter out of the transparency. Cut a hole 9 cm in diameter out of the center of the circle.
3. Stick five toothpicks into Saturn, spaced equally around its equator. Put the transparency on the toothpicks and tape it to them. Sprinkle baking soda on the transparency.
4. Use a peppercorn to represent Titan. Place the peppercorn 72 cm away from Saturn on the same plane as the rings.
5. What do the particles of baking soda represent?

Saturn

The second-largest planet in the solar system is Saturn. The *Voyager* probes showed that Saturn, like Jupiter, has a thick atmosphere made up mainly of hydrogen and helium. Saturn's atmosphere also contains clouds and storms, but they are less dramatic than those on Jupiter. Saturn is the only planet whose average density is less than that of water.

Saturn's Rings When Galileo first looked at Saturn with a telescope, he could see something sticking out on the sides. But he didn't know what it was. A few decades later, an astronomer using a better telescope discovered that Saturn had rings around it. These rings are made of chunks of ice and rock, each traveling in its own orbit around Saturn.

Saturn has the most spectacular rings of any planet. From Earth, it looks as though Saturn has only a few rings and that they are divided from each other by narrow, dark regions. The *Voyager* spacecraft discovered that each of these obvious rings is divided into many thinner rings. Saturn's rings are broad and thin, like a compact disc.

Saturn's Moons Saturn's largest moon, Titan, is larger than the planet Mercury. Titan was discovered in 1665 but was known only as a point of light until the *Voyager* probes flew by. The probes showed that Titan has an atmosphere so thick that little light can pass through it. Four other moons of Saturn are each over 1,000 kilometers in diameter.

Reading Checkpoint What are Saturn's rings made of?

Size of Uranus compared to Earth

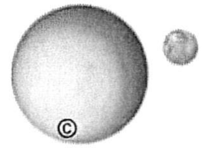
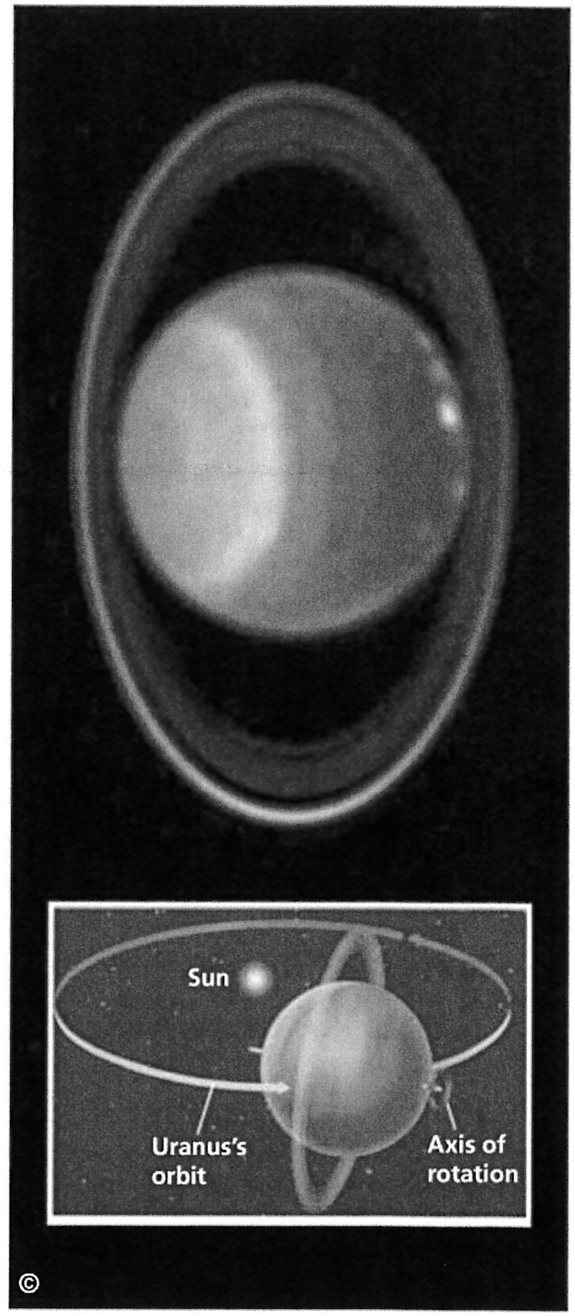


FIGURE 20
Uranus
The false color image of Uranus below was taken by the Hubble Space Telescope. Unlike most other planets, Uranus rotates from top to bottom rather than side to side.
Inferring *How must Uranus's seasons be unusual?*



Uranus

Although the gas giant Uranus (YOOR uh nus) is about four times the diameter of Earth, it is still much smaller than Jupiter and Saturn. Uranus is twice as far from the sun as Saturn, so it is much colder. Uranus looks blue-green because of traces of methane in its atmosphere. Like the other gas giants, Uranus is surrounded by a group of thin, flat rings, although they are much darker than Saturn's rings.

Discovery of Uranus In 1781, Uranus became the first new planet discovered since ancient times. Astronomer William Herschel, in England, found a fuzzy object in the sky that did not look like a star. At first he thought it might be a comet, but it soon proved to be a planet beyond Saturn. The discovery made Herschel famous and started an era of active solar system study.

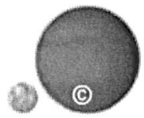
Exploring Uranus About 200 years after Herschel's discovery, *Voyager 2* arrived at Uranus and sent back close-up views of that planet. Images from *Voyager 2* show only a few clouds on Uranus's surface. But even these few clouds allowed astronomers to calculate that Uranus rotates in about 17 hours.

Uranus's axis of rotation is tilted at an angle of about 90 degrees from the vertical. Viewed from Earth, Uranus is rotating from top to bottom instead of from side to side, the way most of the other planets do. Uranus's rings and moons rotate around this tilted axis. Astronomers think that billions of years ago Uranus was hit by an object that knocked it on its side.

Uranus's Moons Photographs from *Voyager 2* show that Uranus's five largest moons have icy, cratered surfaces. The craters show that rocks from space have hit the moons. Uranus's moons also have lava flows on their surfaces, suggesting that material has erupted from inside each moon. *Voyager 2* images revealed 10 moons that had never been seen before. Recently, astronomers discovered several more moons, for a total of at least 27.

Reading Checkpoint Who discovered Uranus?

FIGURE 21
Neptune
The Great Dark Spot was a giant storm in Neptune's atmosphere. White clouds, probably made of methane ice crystals, can also be seen in the photo.



Size of Neptune compared to Earth

Neptune

Neptune is even farther from the sun than Uranus. In some ways, Uranus and Neptune look like twins. They are similar in size and color. **Neptune is a cold, blue planet. Its atmosphere contains visible clouds.** Scientists think that Neptune, shown in Figure 21, is slowly shrinking, causing its interior to heat up. As this energy rises toward Neptune's surface, it produces clouds and storms in the planet's atmosphere.

Discovery of Neptune Neptune was discovered as a result of a mathematical prediction. Astronomers noted that Uranus was not quite following the orbit predicted for it. They hypothesized that the gravity of an unseen planet was affecting Uranus's orbit. By 1846, mathematicians in England and France had calculated the orbit of this unseen planet. Shortly thereafter, an observer saw an unknown object in the predicted area of the sky. It was the new planet, now called Neptune.

Exploring Neptune In 1989, *Voyager 2* flew by Neptune and photographed a Great Dark Spot about the size of Earth. Like the Great Red Spot on Jupiter, the Great Dark Spot was probably a giant storm. But the storm didn't last long. Images taken five years later showed that the Great Dark Spot was gone. Other, smaller spots and regions of clouds on Neptune also seem to come and go.

Neptune's Moons Astronomers have discovered at least 13 moons orbiting Neptune. The largest moon is Triton, which has a thin atmosphere. The *Voyager* images show that the region near Triton's south pole is covered by nitrogen ice.

Reading Checkpoint **Before they could see Neptune, what evidence led scientists to conclude that it existed?**

Math Skills

Circumference

To calculate the circumference of a circle, use this formula:

$$C = 2\pi r$$

In the formula, ≈ 3.14, and *r* is the circle's radius, which is the distance from the center of the circle to its edge. The same formula can be used to calculate the circumference of planets, which are nearly spherical.

Neptune's radius at its equator is about 24,800 km. Calculate its circumference.

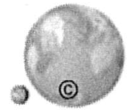
$C = 2\pi r$

2.00 3.14 24,800 km

156,000 km

Practice Problem Saturn's radius is 60,250 km. What is its circumference?

Size of Pluto compared to Earth



Pluto

Pluto is very different from the gas giants. **Pluto has a solid surface and is much smaller and denser than the outer planets.** In fact, Pluto is smaller than Earth's moon.

Pluto has three known moons. The largest of these, Charon, is more than half of Pluto's size.

Pluto's Orbit Pluto is so far from the sun that it revolves around the sun only once every 248 Earth years. Pluto's orbit is very elliptical, bringing it closer to the sun than Neptune on part of its orbit.

Dwarf Planets Until recently, Pluto was considered to be the ninth planet in our solar system. Pluto was always thought to be something of an oddball because of its small size and unusual orbit. Then, in recent years, astronomers discovered many icy objects beyond Neptune's orbit. Some of these were fairly similar to Pluto in size and makeup. Following the discovery of a body that is even larger and farther from the sun than Pluto, astronomers decided to create a new class of objects called "dwarf planets." A dwarf planet, like a planet, is round and orbits the sun. But unlike a planet, a dwarf planet has not cleared out the neighborhood around its orbit. Astronomers classified Pluto and two other bodies as dwarf planets.

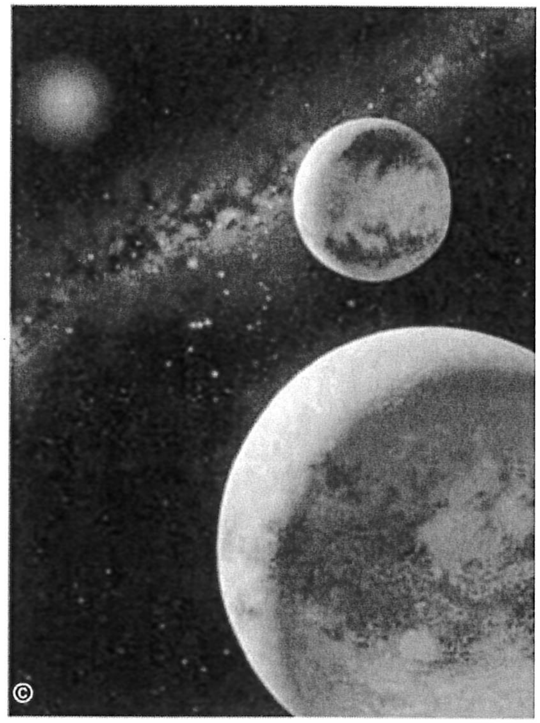


FIGURE 22
Pluto and Charon
The illustration above shows Pluto (lower right) and its moon Charon. Charon is more than half the size of Pluto.

Reading Checkpoint How is Pluto now classified?

Section 4 Assessment

Target Reading Skill Identifying Main Ideas Use your graphic organizer about the structure of the gas giants to help you answer Question 1 below.

Reviewing Key Concepts

1. a. **Describing** How are the gas giants similar to one another? HINT
   b. **Explaining** Why do all of the gas giants have thick atmospheres? HINT
   c. **Listing** List the outer planets in order of size, from smallest to largest. HINT
   d. **Comparing and Contrasting** Compare the structure of a typical terrestrial planet with that of a gas giant. HINT
2. a. **Describing** Describe an important characteristic of each outer planet that helps to distinguish it from the other outer planets. HINT
   b. **Comparing and Contrasting** How is Pluto different from the gas giants? HINT
   c. **Classifying** Why did astronomers reclassify Pluto as a dwarf planet? HINT

Math Practice

3. **Circumference** Jupiter's radius is about 71,490 km. What is its circumference?

Lab zone **Design Your Own Lab**

Speeding Around the Sun

Problem

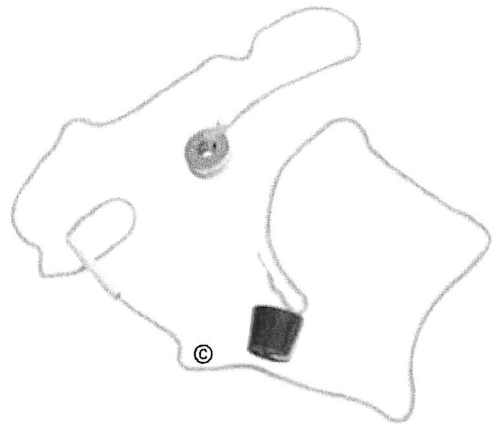
How does a planet's distance from the sun affect its period of revolution?

Skills Focus

making models, developing hypotheses, designing experiments

Materials

- string, 1.5 m
- plastic tube, 6 cm
- meter stick
- weight or several washers
- one-hole rubber stopper
- stopwatch or watch with second hand



Procedure

PART 1 Modeling Planetary Revolution

1. Copy the data table onto a sheet of paper.

Data Table				
Distance (cm)	Period of Revolution			
	Trial 1	Trial 2	Trial 3	Average
20				
40				
60				

2. Make a model of a planet orbiting the sun by threading the string through the rubber stopper hole. Tie the end of the string to the main part of the string. Pull tightly to make sure that the knot will not become untied.
3. Thread the other end of the string through the plastic tube and tie a weight to that end. Have your teacher check both knots.
4. Pull the string so the stopper is 20 cm away from the plastic tube. Hold the plastic tube in your hand above your head. Keeping the length of string constant, swing the rubber stopper in a circle above your head just fast enough to keep the stopper moving. The circle represents a planet's orbit, and the length of string from the rubber stopper to the plastic tube represents the distance from the sun. **CAUTION:** *Stand away from other students. Make sure the swinging stopper will not hit students or objects. Do not let go of the string.*
5. Have your lab partner time how long it takes for the rubber stopper to make ten complete revolutions. Determine the period for one revolution by dividing the measured time by ten. Record the time in the data table.
6. Repeat Step 5 two more times. Be sure to record each trial in a data table. After the third trial, calculate and record the average period of revolution.

PART 2 Designing an Experiment

7. Write your hypothesis for how a planet's period of revolution would be affected by changing its distance from the sun.
8. Design an experiment that will enable you to test your hypothesis. Write the steps you plan to follow to carry out your experiment. As you design your experiment, consider the following factors:
   - What different distances will you test?
   - What variables are involved in your experiment and how will you control them?
   - How many trials will you run for each distance?
9. Have your teacher review your step-by-step plan. After your teacher approves your plan, carry out your experiment.

Analyze and Conclude

1. **Making Models** In your experiment, what represents the planet and what represents the sun?
2. **Making Models** What force does the pull on the string represent?
3. **Interpreting Data** What happened to the period of revolution when you changed the distance in Part 2? Did your experiment prove or disprove your hypothesis?
4. **Drawing Conclusions** Which planets take less time to revolve around the sun—those closer to the sun or those farther away? Use the model to support your answer.
5. **Designing Experiments** As you were designing your experiment, which variable was the most difficult to control? How did you design your procedure to control that variable?
6. **Communicating** Write a brief summary of your experiment for a science magazine. Describe your hypothesis, procedure, and results in one or two paragraphs.

More to Explore

Develop a hypothesis for how a planet's mass might affect its period of revolution. Then, using a stopper with a different mass, modify the activity to test your hypothesis. Before you swing your stopper, have your teacher check your knots.