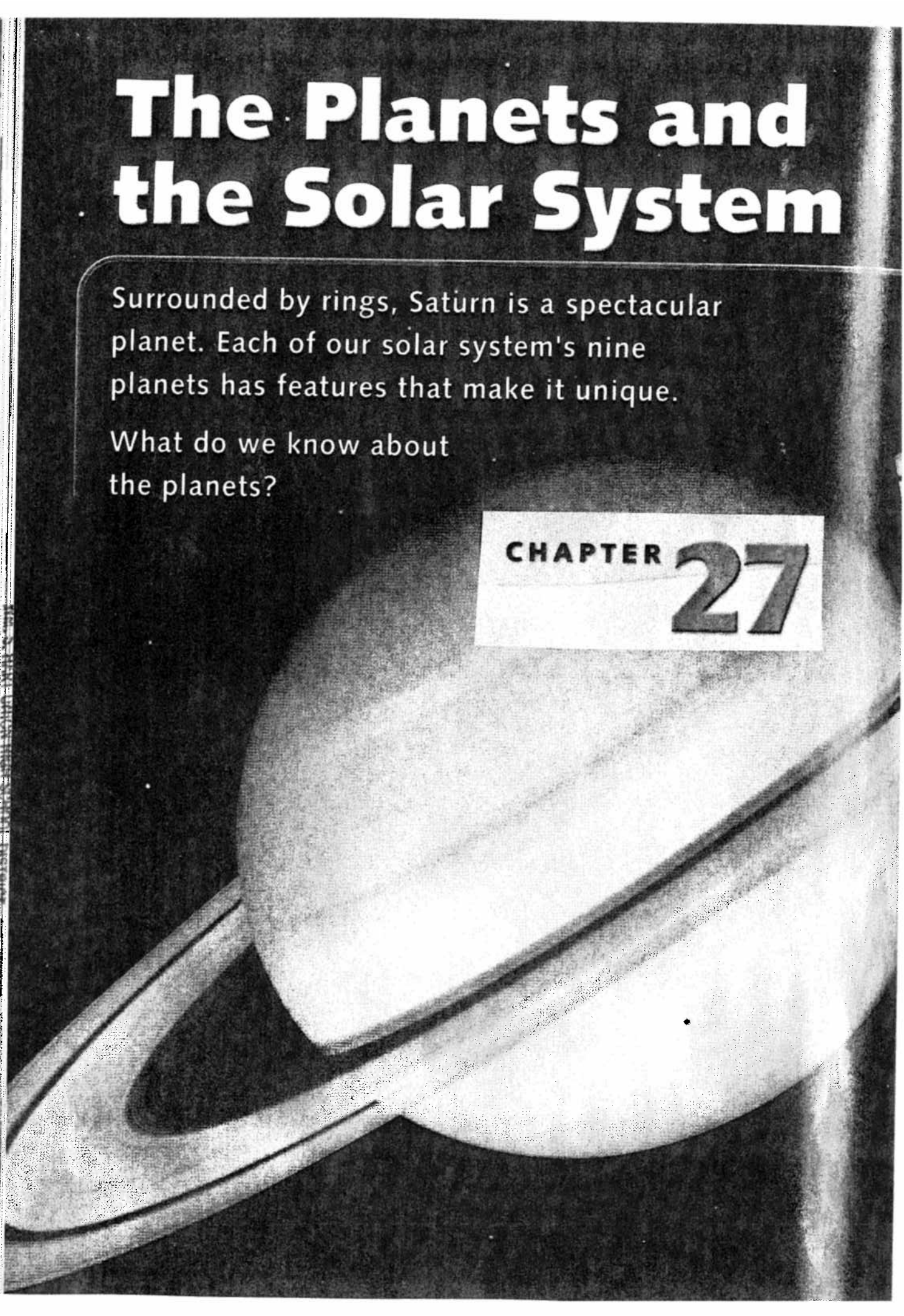
The Planets and the Solar System

Surrounded by rings, Saturn is a spectacular planet. Each of our solar system's nine planets has features that make it unique.

What do we know about the planets?

CHAPTER 27



CHAPTER 27

PREVIEW

▶ FOCUS QUESTIONS

In this chapter you will study the planets of Earth's solar system and learn more about the key questions below.

Section 1 How are the inner planets alike?

Section 2 How are the Jovian planets different from Earth?

Section 3 What are some of the characteristics of planetary moons?

Section 4 What other objects are part of the solar system?

▶ REVIEW TOPICS

As you investigate the planets, you will need to use information from earlier chapters.

- the movement of planets **(pp. 577–580)**
- the moon's origin **(pp. 556–557)**
- properties of the moon **(p. 557)**

▶ READING STRATEGY

SET A PURPOSE

Before each section, read the appropriate focus question as well as the questions at the end of the section. Use those questions to set a purpose for reading each section.

At our Web site, you will find the following Internet support for this chapter.

DATA CENTER

EARTH NEWS

VISUALIZATIONS

- Distances between the Planets
- Radar Mapping of Venus
- Comet's Passage through the Solar System
- Meteor Showers

LOCAL RESOURCES

CAREERS

INVESTIGATIONS

- How Fast Does the Wind Blow on Jupiter?
- What Processes Shape Planetary Surfaces?

27.1

KEY IDEA

The four planets closest to the sun all have a rocky crust, dense mantle layer, and very dense core.

KEY VOCABULARY

- inner planets
- outer planets

The Inner Planets

The sun is at the center of the solar system. Around it orbit nine planets, each with unique characteristics. Although astronomers have known about the existence of other planets for centuries, it's only within the last few decades that technology has given scientists an up-close look at our nearest neighbors in space.

Two Planetary Neighborhoods

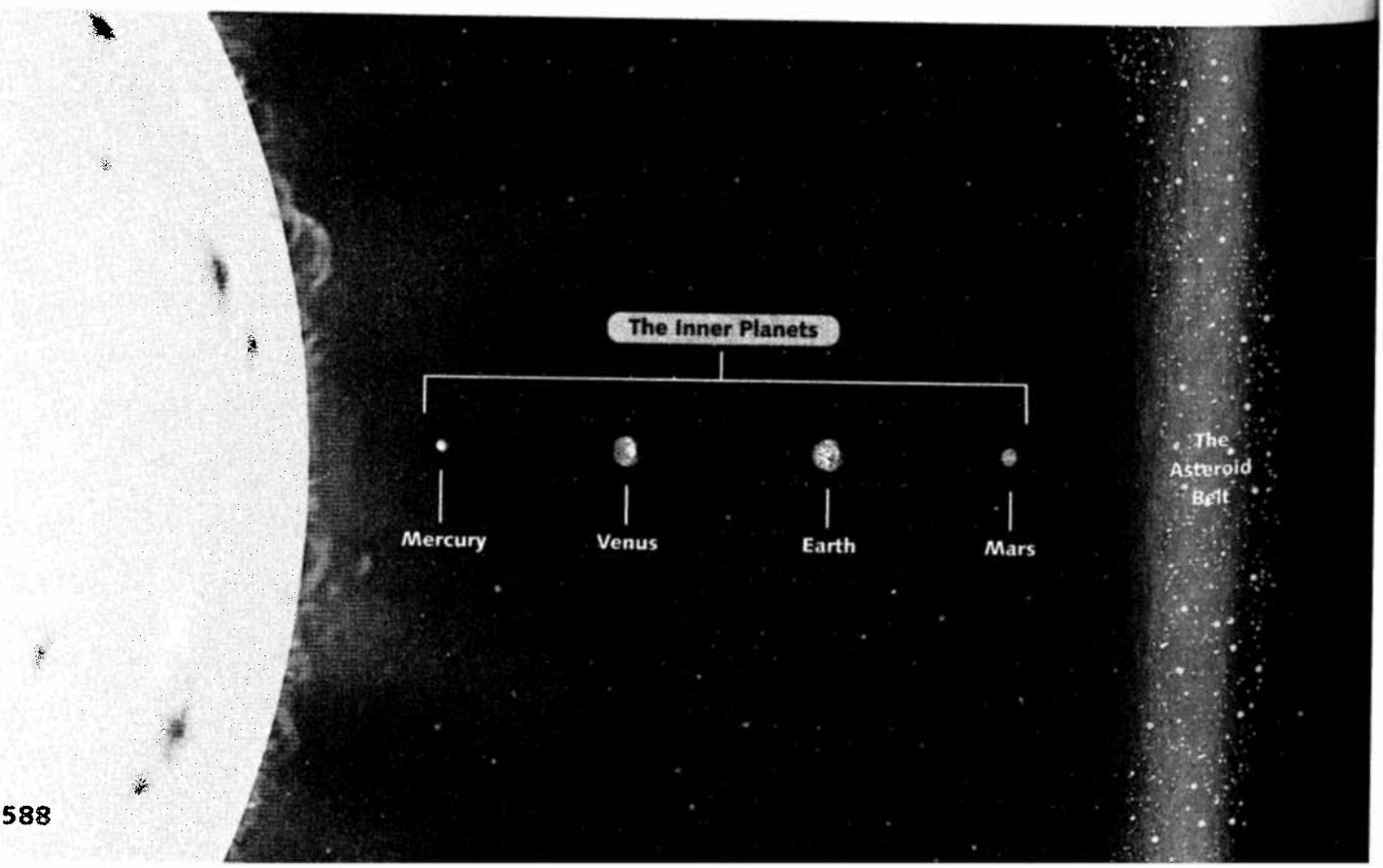
The planets in our solar system are divided into two groups. The four nearest the sun—Mercury, Venus, Earth, and Mars—are called the **inner planets.** All of the inner planets have rocky crusts, dense mantle layers, and very dense cores. Because of their earthlike characteristics, these planets are sometimes called the terrestrial (earthlike) planets.

Just beyond the orbit of Mars is a belt of small bodies called asteroids. This asteroid belt separates the inner planets from the **outer planets,** Jupiter, Saturn, Uranus, Neptune, and Pluto. The first four of these planets, called the Jovian, or Jupiter-like, planets, are considerably larger than Earth. They are gaseous, with an outer layer that is mostly hydrogen gas. Closer to the planet's center, the hydrogen is compressed to a hot liquid. The Jovian planets are much less dense than Earth, and all have ring systems.

Pluto is the oddity of the solar system. It is not dense enough to be considered a terrestrial planet, and it is too small to be a Jovian planet. You will read more about the outer planets in the next section.

VISUALIZATIONS
CLASSZONE.COM
Examine the vast distances between planets in the solar system.
Keycode: ES2701

THE SOLAR SYSTEM This illustration shows the relative sizes of the planets but does not represent the distance between them.



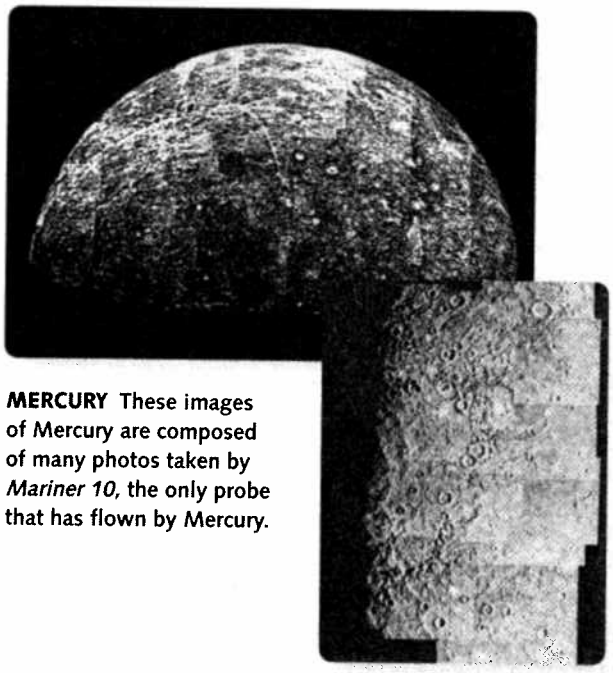
Mercury

Mercury is the planet nearest the sun. Of all the planets, it orbits the sun in the shortest period of time—88 Earth days. Mercury is the smallest of the four terrestrial planets. Its diameter is about 38 percent that of Earth, as is its gravity. Mercury's magnetic field is about one percent as strong as Earth's.

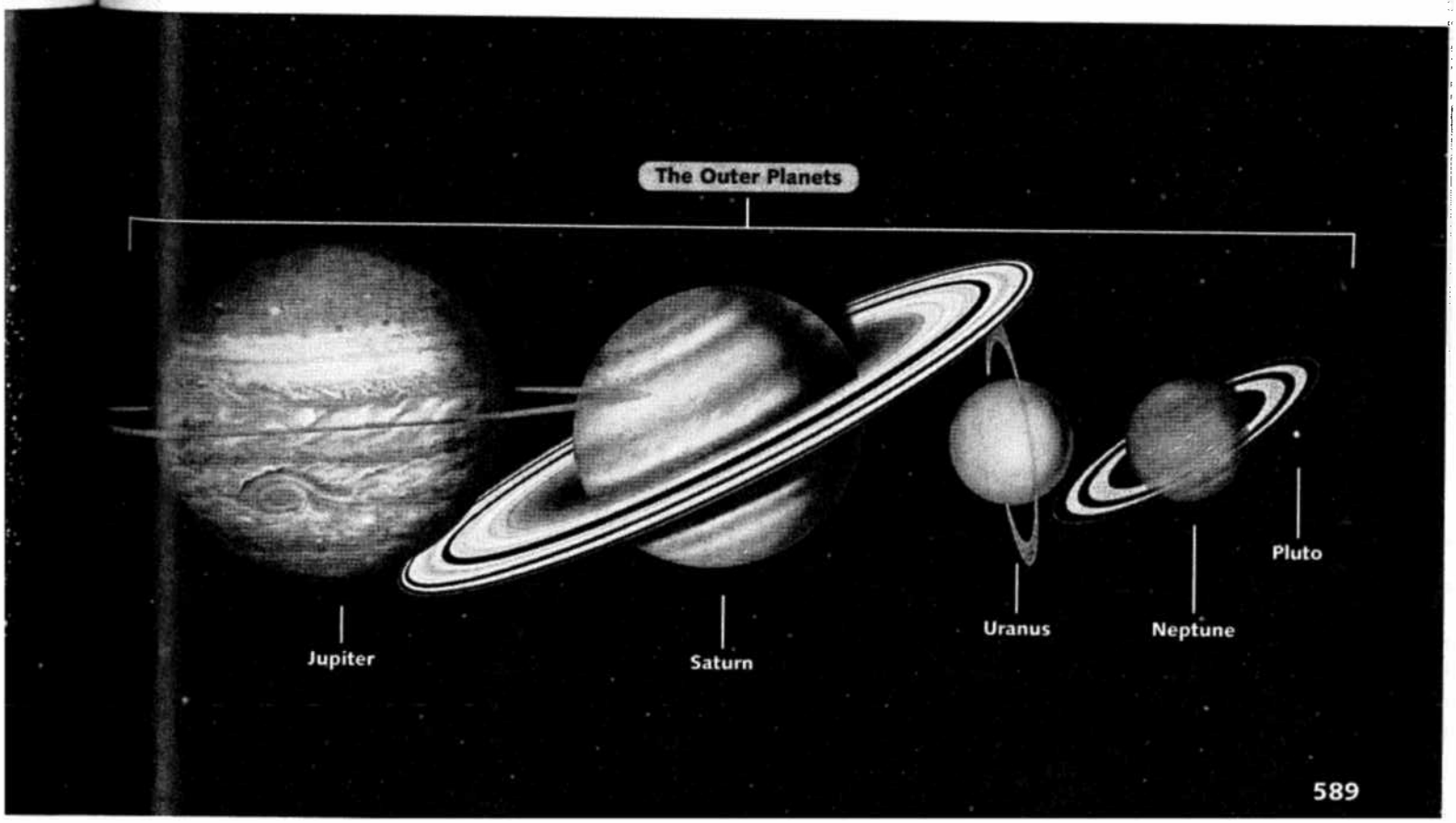
Little was known about Mercury until *Mariner 10* photographed it in 1974 and 1975. These photographs show that Mercury's surface is heavily cratered, similar to Earth's moon. Like the craters on Earth's moon, these impact craters probably formed when huge rocks smashed into Mercury. Impact craters are Mercury's most abundant landform. The rest of the surface is smooth plains that may have been formed by lava flowing out of cracks in the surface.

Mercury turns on its axis once every 59 days. This slow rate, combined with Mercury's nearness to the sun, causes daytime temperatures of more than 400°C. In the nighttime, heat radiates away quickly and the temperature may be nearly −200°C.

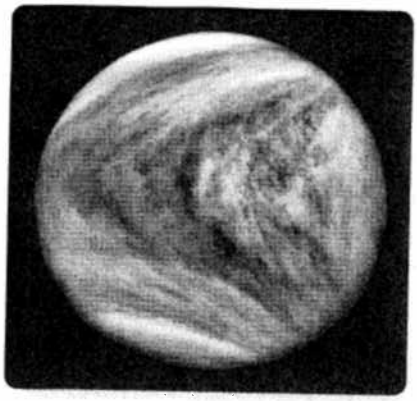
Mercury has weak gravity, which prevents it from retaining an atmosphere. High daytime temperatures cause any particles above its surface to move at high speeds, allowing gases to escape into space.



MERCURY These images of Mercury are composed of many photos taken by *Mariner 10*, the only probe that has flown by Mercury.



Venus



VENUS'S surface is hidden by thick clouds of sulfuric acid.

Venus has been called Earth's sister planet because the two are near each other and are similar in diameter, mass, and gravity. Unlike Earth, however, Venus has a very weak or nonexistent magnetic field. Unlike the other planets, Venus rotates from east to west. Venus rotates on its axis very slowly, completing one rotation every 243 days. It orbits the sun in 225 days, which means one day on Venus is longer than one year on Venus.

Thick, pale yellow clouds in Venus's atmosphere make its surface impossible to see from Earth. Most of our knowledge of Venus's surface comes from radar-mapping done by the *Magellan* spacecraft, beginning in 1990. Radar images show that the surface of Venus has some similarities to Earth. *Magellan* revealed a landscape dominated by volcanic features, faulting, and impact craters. About 80 percent of the surface is covered with lava. Venus has fault and fracture systems as well, indicating that tectonic activity has occurred in the past. Whether its volcanoes continue to erupt and faulting is still going on is uncertain. The oldest crust on Venus is estimated to be about 800 million years old; the oldest crust on Earth is about 4.3 billion years old.

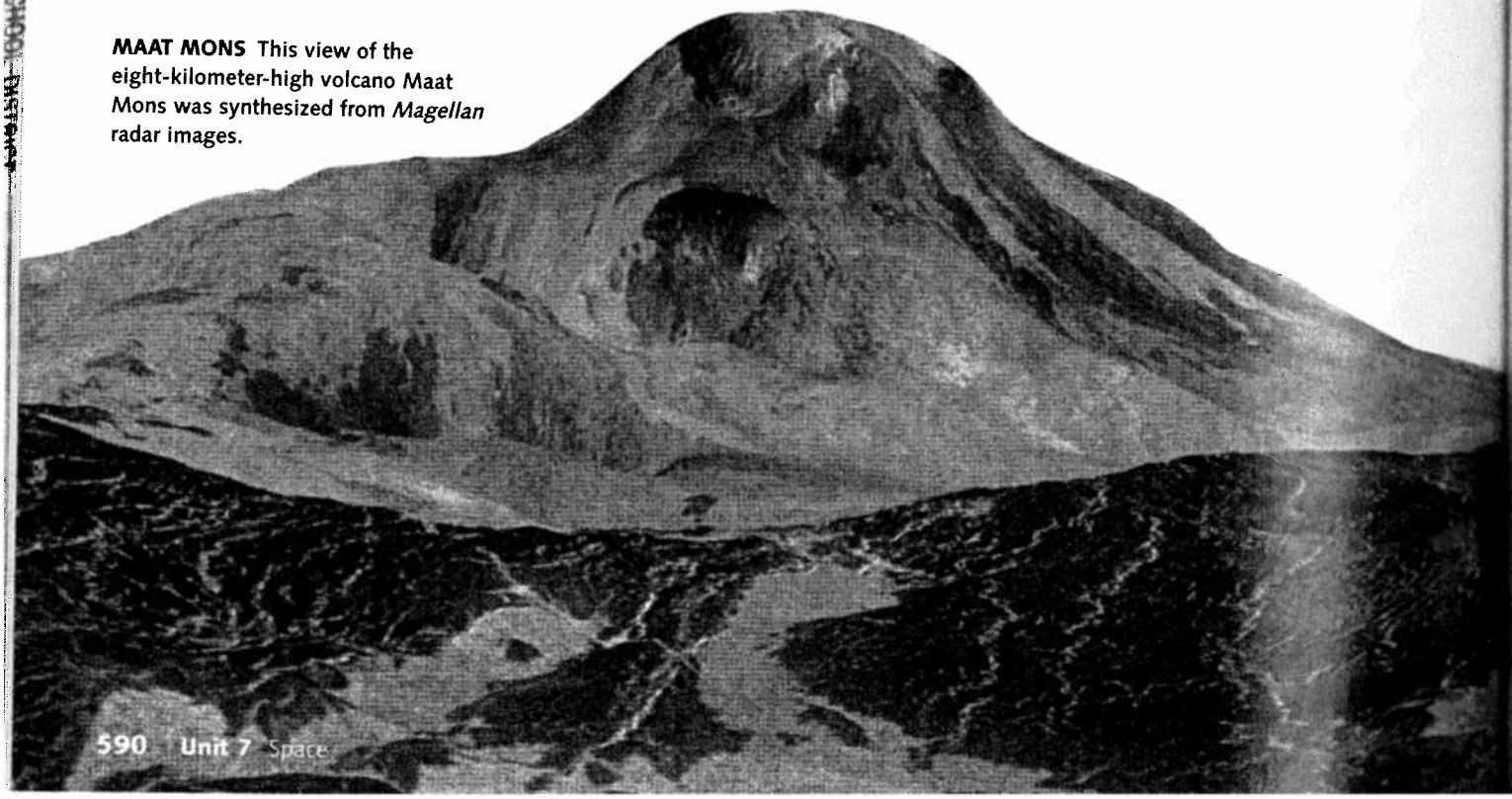
In 1985, two balloons carrying weather instruments were placed in the atmosphere of Venus. Their data showed that the dense atmosphere is mostly carbon dioxide with about 3 percent nitrogen. Venus's yellow clouds are made of droplets of concentrated sulfuric acid. The surface atmospheric pressure is about 90 times greater than it is on Earth.

Despite Venus's thick clouds, its surface is very hot. Carbon dioxide in the atmosphere acts much like a greenhouse. The carbon dioxide atmosphere traps heat radiated from the surface of Venus and keeps the temperature high. The result of this greenhouse effect is a surface temperature of about 475°C.

VISUALIZATIONS
CLASSZONE.COM

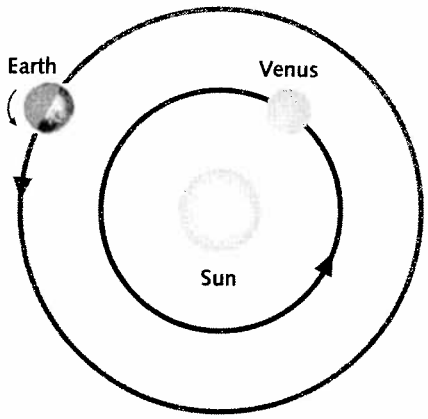
Observe how radar was used to map Venus.
Keycode: ES2702

MAAT MONS This view of the eight-kilometer-high volcano Maat Mons was synthesized from *Magellan* radar images.

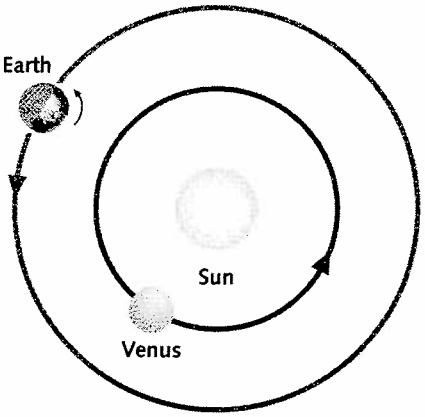


Evening and Morning Stars

Venus is visible to observers on Earth at either evening or morning twilight almost all year.



EVENING STAR When Venus is behind Earth in its orbit, the sun sets first and Venus is seen in the evening twilight of the western sky. At such times, Venus is called an evening star. It may remain visible as long as three hours after sunset.



MORNING STAR When Venus is ahead of Earth in its orbit, it rises before the sun and is seen in the eastern sky as a morning star.

Venus can be seen from Earth as a morning or evening star, as can Mercury. However, Mercury is much more difficult to see because its orbit is closer to the sun and it is smaller and less bright than Venus.

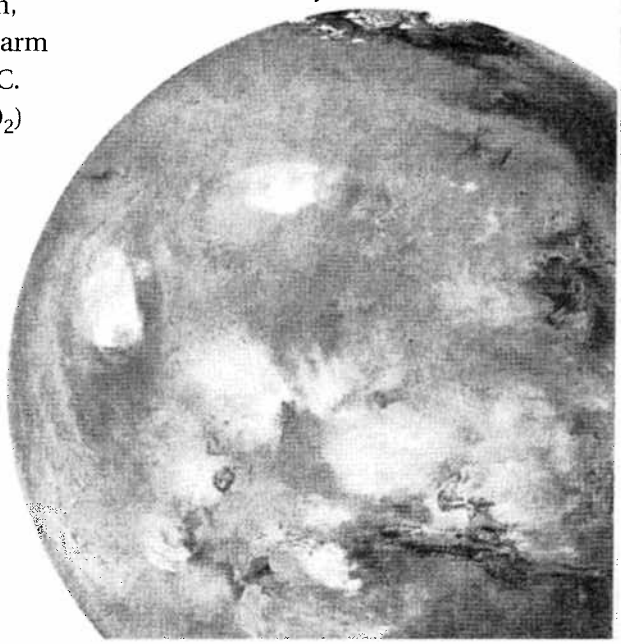
Mars

Mars is the fourth planet from the sun and the first planet outside Earth's orbit. Mars takes 687 days to orbit the sun. Its diameter is about one half that of Earth. The gravity of Mars is about two fifths of Earth's. Mars has a very weak magnetic field.

Mars's axis is tilted at almost the same angle and in the same direction as Earth's. This tilt gives Mars four seasons similar to Earth's. However, because a Martian year is about twice as long as an Earth year, each Martian season is also twice as long. Because it is farther from the sun, Mars is colder than Earth. On a summer day, some areas may be as warm as 27°C, but on a winter night the temperature drops as low as −133°C. The thin Martian atmosphere is about 95 percent carbon dioxide (CO_2) and 5 percent nitrogen and argon, with traces of other gases. Because the atmosphere is so thin, atmospheric pressure is less than 1 percent that of Earth.

Like Earth, Mars has polar ice caps. Both ice caps are probably water ice covered by frozen CO_2. The caps increase in size during each Martian winter and shrink during each summer. The temperature difference between the polar caps and soil warmed by the spring sun leads to strong winds and great swirling dust storms that often cover the entire planet.

MARS Scattered clouds float above the Martian surface in this photo mosaic taken by the Mars Global Surveyor.



MARS Canyons, mountains, and valleys mark the surface of Mars.

Cameras aboard several spacecraft have photographed the surface of Mars. Spacecraft have also visited the surface to take close-up photographs, to record quakes and weather, and to test soil samples. Photographs show that Mars's northern hemisphere is a smooth lowland plain of volcanic material, with few craters. Its southern hemisphere is a highland fractured by many large craters and cut by small channels.

Rising above the northern plains are several extinct volcanoes. The largest, also the largest known volcano in the solar system, is the shield volcano Olympus Mons (Mount Olympus). It is more than 500 kilometers across and about 26 kilometers high. In comparison, Earth's highest volcano, Mauna Loa, rises about 9 kilometers above the Pacific Ocean floor. Unlike many of Earth's volcanoes, the formation of Martian volcanoes does not seem to be related to plate motions, because the crust of Mars is one solid piece. Mars's crust varies in thickness from 80 kilometers in the southern hemisphere to about 35 kilometers in the north.

Cutting across the craters of the southern hemisphere is the Valles Marineris, a canyon system as long as the United States is wide. About 4 billion years ago, Mars may have had a thick atmosphere, blue skies, and abundant liquid water on its surface. The depths of Valles Marineris may have once held lakes of liquid water. Over the next billion years or so, however, most of Mars's atmosphere disappeared. At present, liquid water cannot exist on the surface of Mars, because it would quickly boil or freeze. However, much of the liquid water that once flowed across Mars may be trapped as ice beneath the surface.

Is there life on Mars? Since liquid water probably existed on Mars's surface in the past, it is possible that primitive life developed there before the atmosphere thinned and the surface water froze. If liquid water still exists in geothermal pools beneath the surface of Mars, then Martian life may still exist. Whether life existed or still exists on Mars is a question that will be answered only with further exploration.

25-Minute
Mini LAB

Design a Martian Calendar

Materials

- graph paper
- colored pencils

Procedure

1. A Martian year includes 668.6 Martian days, and you're designing the first calendar. How many days are in your week? In your month?
2. On graph paper, outline a calendar. Make one square represent each day.
3. Color in the first month. Use different colors to fill in the other months, and label days and months.

Analysis

How many months are on your calendar? How did you compensate for the fact that the Martian year doesn't include a whole number of days?

27.1 *Section Review*

1. Into what two groups are the planets divided? What are the main characteristics of each group?
2. Why does Mercury have no atmosphere?
3. Why is the surface of Venus so hot?
4. Why does Mars have seasons?
5. **CRITICAL THINKING** Why does neither Venus nor Mercury appear high in the night sky on Earth?
6. **BIOLOGY** Why is it more likely that life existed on Mars billions of years ago rather than it does now?

SCIENCE & Technology

Seeking the Red Planet's Secrets

Five successful landings of probes on the Martian surface have told us a great deal about our planetary neighbor.

What other discoveries lie ahead?

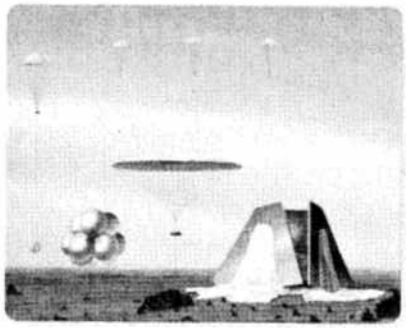
Mars is enough like our own planet to be familiar, yet alien enough to inspire curiosity. Was there ever liquid water on Mars? Could life have existed there in the past—or could it exist now?

Earth scientists have been trying to reach the red planet for decades. Attempts to send a probe to Mars started in 1960, with the Soviet Union's Mars probe *1960A*, which failed to reach Earth orbit. Not until 1965 did a probe from the United States, *Mariner 4*, succeed in reaching Mars. It flew within 6,118 miles of the Martian surface and provided the first close-up photos of the planet. Successive *Mariner* missions came even closer to Mars, and one, *Mariner 9*, became the first U.S. spacecraft to enter orbit around another planet in November 1971.

The *Viking* missions, which took place in the late 1970s, gave scientists a close look at the surface, providing more than 52,000 photos before they were shut down.

The *Mars Global Surveyor*, launched on November 7, 1996, and still in orbit around Mars, has made detailed maps of the planet's terrain. Also in 1996, *Mars Pathfinder*, consisting of a lander and a surface rover named *Sojourner*, sent back spectacular photos from the surface of Mars. In 2004, the rovers *Spirit* and *Opportunity* found evidence that water once flowed on Mars.

NASA plans future missions that will not only land spacecraft on the planet but also return them to Earth with soil samples. For now, scientists are still analyzing the evidence they have to try to unravel the secrets of Mars. ■



AIR-FILLED BALLOONS cushioned *Mars Pathfinder's* landing, providing an inexpensive solution to the problem of having the spacecraft land on the planet intact.

Extension

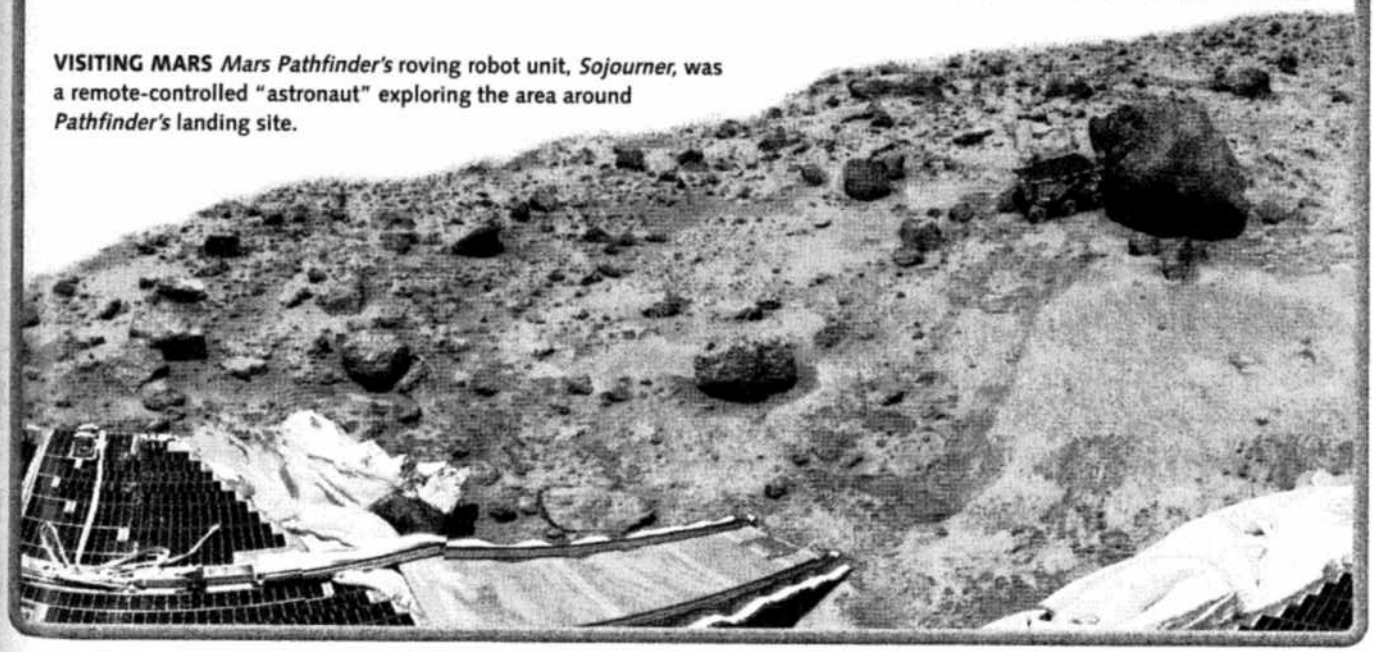
SCIENCE NOTEBOOK

Using what you know about Mars's environment and geology, design an experiment to be conducted on a future Mars mission.

DATA CENTER CLASSZONE.COM

Find out about the latest missions to Mars.

Keycode: ES2703



VISITING MARS *Mars Pathfinder's* roving robot unit, *Sojourner*, was a remote-controlled "astronaut" exploring the area around *Pathfinder's* landing site.

27.2

KEY IDEAS

Four of the outer planets are gaseous and huge compared to Earth.

Pluto is the smallest and coldest planet in our solar system.

The Outer Planets

Beyond the orbit of Mars, the solar system becomes a very strange place of huge gaseous planets, peculiar ring systems, and many strange moons. The three outermost planets—Uranus, Neptune, and Pluto—were discovered only after the invention of the telescope.

The Jovian Planets

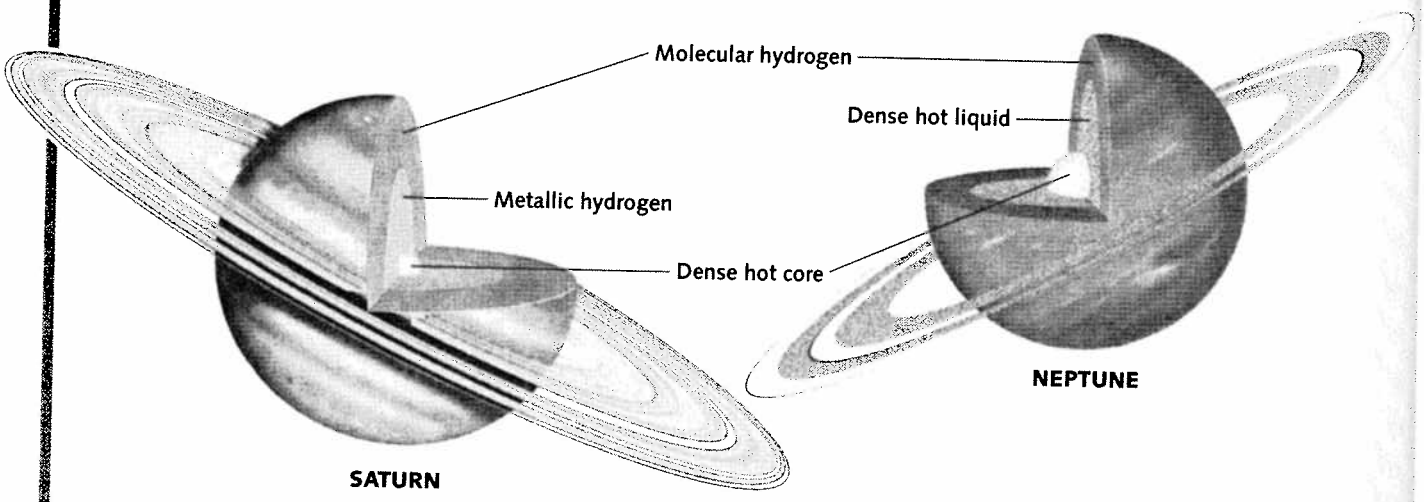
The Jovian planets—Jupiter, Saturn, Uranus, and Neptune—are unlike the terrestrial planets in several ways. First, Jovian planets are much larger. The smallest Jovian planet, Uranus, is nearly 15 times more massive than the largest terrestrial planet, Earth. Second, Jovian planets do not have solid surfaces; instead the "surface" of each one consists of the uppermost gas layer. Third, Jovian planets are composed mainly of the light elements hydrogen and helium, while terrestrial planets are made of iron, silicon, oxygen, and other heavy elements.

All Jovian planets have a three-layered structure. The temperature and density of the planets' interiors increase with depth.

All the Jovian planets have ring systems. The ring systems have three common properties. First, they consist of many particles in independent orbits around the planet. Second, the rings are closer to the planet than its major moons. Third, the rings orbit over the planet's equator. Saturn's rings are highly visible; the faint rings of the other Jovian planets were discovered in the late 1970s.

The Jovian Planets

Features common to the Jovian planets include ring systems and layers of hydrogen. (Not to scale)

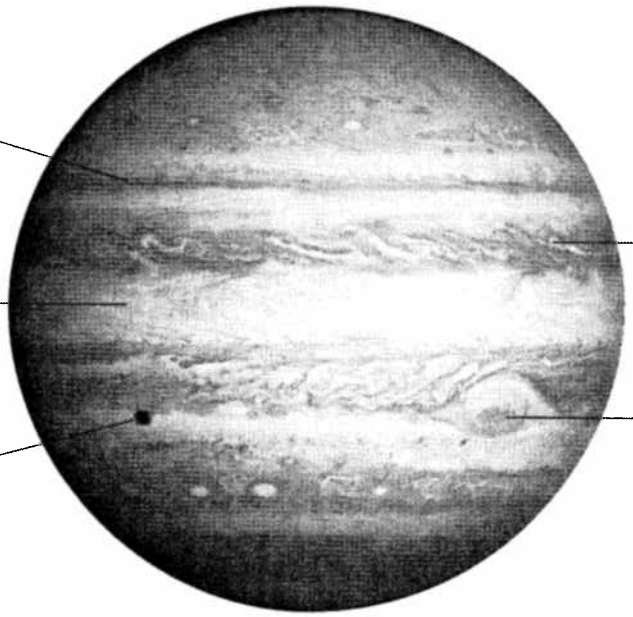


For Jupiter and Saturn, hot liquid hydrogen becomes compressed into a state with properties similar to those of liquid metal.

Uranus and Neptune are not large enough to compress hydrogen into a metallic state. Instead, these planets may have dense interiors of water, methane, and ammonia.

Jupiter's surface

JUPITER is the largest planet in the solar system and has the most striking surface features of any planet.



Jupiter

Jupiter, the fifth planet from the sun, takes 11.9 Earth years to complete one orbit. It rotates faster than any other planet—once in just under 10 hours. It is the largest planet in the solar system and has more than twice the total mass of all other planets combined.

Jupiter has the strongest known magnetic field of the solar system's planets. As on Earth, the interaction between the solar wind and the magnetic field causes brilliant auroras, colored displays of light.

Jupiter radiates about twice as much heat back to space as it receives from the sun. The extra heat is thought to come from Jupiter's original heat of formation and from contraction due to gravity.

The Great Red Spot is the most striking feature of Jupiter's surface. However, it is just one of several spots. Some spots appear and disappear quickly, while others remain for decades. Photographs indicate that the spots may be relatively calm areas that rotate slowly within the turbulent atmosphere.

On December 7, 1995, the *Galileo* probe successfully entered Jupiter's atmosphere, the first time an Earth spacecraft had entered the atmosphere of a giant planet. To scientists' surprise, the probe found no thick, dense clouds. The probe also revealed that the temperatures and pressures in the upper atmosphere were higher than scientists had expected, and the deep atmosphere is convective. These discoveries have raised intriguing questions for scientists to explore over the coming years.

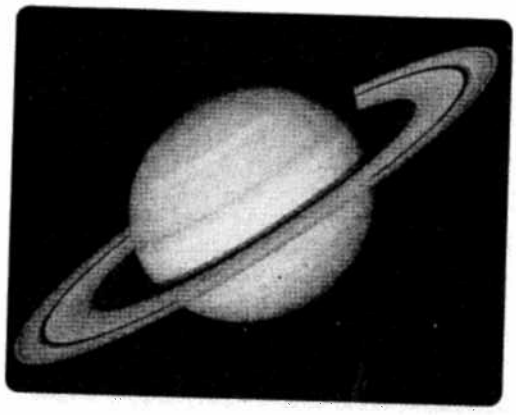
INVESTIGATIONS
CLASSZONE.COM

How Fast Does the Wind Blow on Jupiter?
Analyze images of Jupiter's atmospheric features to calculate wind speeds.
Keycode: ES2704

Saturn

Saturn, the sixth planet from the sun, takes nearly 30 Earth years to complete one orbit. Saturn turns on its axis about every 10 hours. Like Jupiter, the surface of Saturn has colored zones and belts, which are areas of rising and sinking gases. Saturn, however, has fewer zones and belts than Jupiter. Saturn has the lowest density of any planet. In fact, its density is lower than that of water. If there were an ocean of water big enough, Saturn would be able to float on it.

Saturn radiates more energy than it receives from the sun. Like Jupiter, it has sources of internal heat. Saturn's magnetic field is weaker than Jupiter's, but still much stronger than Earth's magnetic field.



SATURN has the most visible ring system of all the Jovian planets. The rings are believed to be made of billions of chunks of ice.

CAREER

Mission Specialist

Astronauts come from all walks of life. However, despite their diverse backgrounds, all of them are accomplished professionals within their fields and are in excellent physical shape.

During the course of their training, they become accustomed to weightlessness, learn to work as a team, and acquire the skills needed to respond to emergencies in space. Some astronauts combine space exploration with scientific research. A mission specialist is an astronaut with expertise in fields such as astronomy, engineering, biology, meteorology, or medicine. Aboard the space shuttle, mission specialists perform scientific experiments and assist with other missions, such as the deployment of satellites.

All American astronauts are employees of the National Aeronautics and Space Administration (NASA). To become a mission specialist, candidates apply to NASA. Applicants must have at least a bachelor's degree in engineering, biological sciences, physical sciences, or math. Most candidates find that a solid background in math and science, starting in high school, is advantageous. Advanced degrees and work experience are also helpful. Chosen candidates must meet strict physical and medical requirements. They then complete a two-year training program before being assigned to space missions. Although the preparation is demanding and the job potentially dangerous, mission specialists are motivated by the knowledge that they may have the rare opportunity to travel in space. ■

MAE JEMISON became the first woman of color in space when she voyaged in the space shuttle *Endeavor* on September 12, 1992.

CAREERS
CLASSZONE.COM

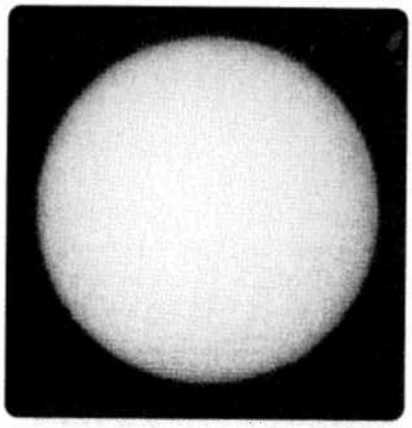
Learn more about becoming an astronaut.
Keycode: ES2705

Uranus

Uranus (YUR-uh-nuhs), the seventh planet from the sun, takes 84 Earth years to complete one orbit. Because Uranus is not easily visible to the unaided eye from Earth, it was not discovered until 1781, when more powerful telescopes became available. Uranus is about 19 times farther from the sun than Earth is. Sunlight there is about 370 times fainter than on Earth, and the average surface temperature is only about −200°C.

Uranus turns on its axis once every 17.2 hours. More unusual is its axis of rotation—it is tipped almost completely over, so that Uranus orbits the sun on its side. Some scientists think that the planet was tipped by a collision with an Earth-sized mass early in the history of the solar system.

When *Voyager 2* flew past Uranus in 1986, it discovered something surprising about the planet's magnetic field. Even though the planet is tipped over, the magnetic field is not. For most planets, the axis of rotation and the magnetic field differ by only a few degrees. On Uranus the difference is 60 degrees. This difference causes the planet's magnetic field to trace a spiral pattern in the solar wind as the planet rotates.



URANUS has a turquoise color, due to the methane gas in its atmosphere.

Neptune, Pluto, and Charon

Neptune, the most distant of the Jovian planets, was discovered in 1846, after astronomers had predicted its existence mathematically. Its period of rotation is 16.1 Earth hours, and it takes about 165 years to orbit the sun.

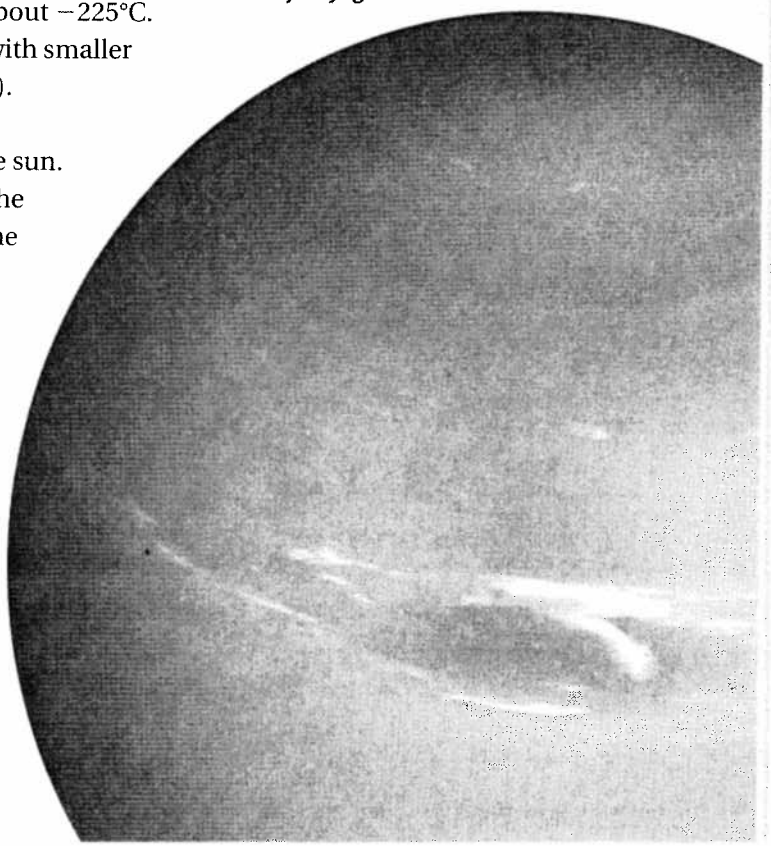
Like Uranus, Neptune has some peculiarities. In 1989, *Voyager 2* discovered that the planet's magnetic axis is tipped 47 degrees in relation to its axis of rotation. In addition, it is offset from the planet's center by about 13,500 kilometers. Scientists think that motions of a conductive material (possibly water) in its middle layers generate the magnetic field.

Neptune is a harsh planet, where winds have been clocked at 2000 kilometers an hour, and the mean temperature is about −225°C. Neptune's atmosphere is mostly hydrogen (74 percent) with smaller amounts of helium (25 percent) and methane (1 percent).

Although it is usually the eighth planet from the sun, Neptune occasionally becomes the ninth planet from the sun. Every 248 years, Pluto's peculiar orbit brings it closer to the sun than Neptune. When this happens, Pluto becomes the eighth planet and Neptune the ninth for about 20 years. This switch happened most recently in 1979, and Pluto returned to its place as the outermost planet on February 11, 1999.

While not always the most distant planet, Pluto is always the smallest, with a diameter estimated to be about 2300 kilometers (in comparison, the distance from New York City to Houston is 2287 kilometers). It is smaller than seven of the solar system's moons, including Earth's moon.

NEPTUNE The great dark spot has vanished since this photo was taken by *Voyager 2*.



Scientific Thinking

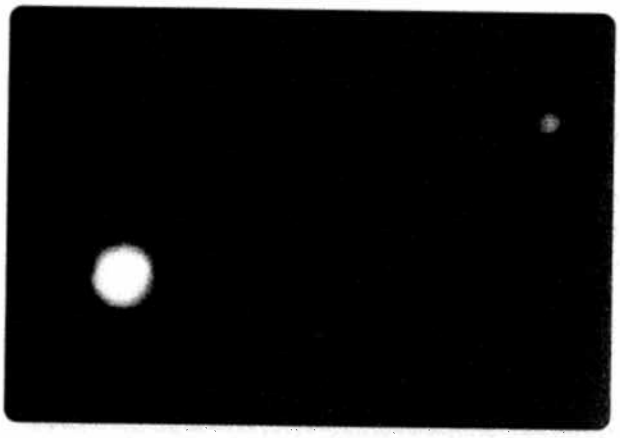
INFER

The Kuiper Belt, at the far edge of the solar system, is believed to be the source of short-period comets. Scientists think it is possible that the belt contains as-yet-unidentified objects that are as large as Charon or even Pluto. Do you think that Pluto originated in this belt? Explain your reasoning.

Pluto was thought to be larger than it is until 1978, when astronomers discovered that it had a moon about half its size. Charon, Pluto's moon, has a diameter of about 1200 kilometers. Given their similarity in mass, some scientists consider Pluto and Charon to be a double planet, rather than a planet-moon system.

Pluto is so far away from Earth—an average of 39.5 AUs from the sun—that it was not discovered until 1930. Its surface temperature probably varies between −235°C and −210°C; at such temperatures, most of its atmosphere is frozen, thawing out slightly when the planet is nearest the sun. Although its density is not known, scientists believe it consists of about 70 percent rock and 30 percent water.

Because no spacecraft have yet visited it, Pluto remains largely a mystery. However, it shows us that we still have much to learn about our own solar system, even as we turn our attention to other, distant systems.



PLUTO AND CHARON have the smallest size difference of all the solar system's planet-moon systems.

27.2 Section Review

1. What are some main differences between the Jovian and terrestrial planets?
2. Why do Jupiter and Saturn give off more heat than they receive from the sun?
3. What is unusual about Uranus's axis of rotation?
4. **CRITICAL THINKING** Scientists have observed areas of light and dark on Pluto's surface. Given what you know about this planet, what do you think the areas might be?
5. **MATHEMATICS** In what year will Pluto once again be the eighth planet from the sun?

Planetary Satellites

27.3

KEY IDEA

Of the inner planets, only Earth and Mars have moons; all outer planets have moons, some of which are quite large.

Bodies that revolve around planets are called satellites, or moons. Except for Mercury and Venus, each planet has at least one natural satellite.

Satellites of Earth and Mars

The moon is Earth's only natural satellite. Mars has two tiny moons, Phobos (FOH-buhs) and Deimos (DEE-mohs). Both have irregular shapes and are marked with impact craters. Phobos, the larger of the two, is only 27 kilometers at its widest. It is closer to Mars than Deimos, and circles the planet more than three times a day.

DEIMOS

PHOBOS

DEIMOS AND PHOBOS These illustrations depict the Martian moons' irregular shapes and cratered surfaces.

Jupiter's Moons

Jupiter has at least 63 moons. The four largest—Io, Europa, Ganymede, and Callisto—are known as the Galilean satellites in honor of their discoverer, Galileo Galilei. Between 1996 and 2003, a spacecraft called *Galileo* investigated these moons further and made some surprising discoveries.

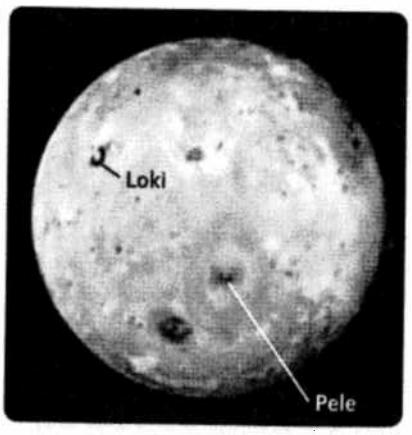
Io, nearest of the Galilean satellites to Jupiter, is geologically active. At least nine active volcanoes have been observed, and some have been photographed in eruptions that reach more than 300 kilometers above the surface. The sulfur, sulfur dioxide, and other sulfur compounds from the volcanoes cause Io's distinctive surface color, which varies from yellow-orange to red to black. Unlike most solar-system objects, Io shows no signs of impact craters. If craters existed on Io, they have been erased by volcanic material.

Io's density is about 3.5 g/cm^3, which is close to that of Earth's moon. Io has a high-altitude ionosphere, detected by the *Galileo* spacecraft, and is thought to have a very thin sulfur-dioxide atmosphere. Its surface is covered with layers of sulfur and frozen sulfur dioxide.

The *Galileo* spacecraft also found that Io has an iron core that may take up half its diameter of over 3600 kilometers. A layer of molten silicate rock surrounds the core. Io gets its internal heat from friction due to tidal forces that change in strength continuously as Io moves along its elliptical orbit.

Europa, next out from Jupiter, was also found to have an atmosphere by the *Galileo* spacecraft. Europa's smooth and shiny white surface appears to

VOLCANOES ON IO Loki and Pele are two volcanoes on Io.



EUROPA'S SURFACE This false-color, high-resolution image of Europa's surface shows what appear to be icebergs floating atop a liquid ocean. Notice that some of the structures fit together like puzzle pieces.

be a shell of water ice up to 100 kilometers thick. Europa has relatively few craters on its surface, suggesting that recent geologic activity—possibly within the last few million years—has erased the scars of meteorite bombardments. Europa's surface is marked by a crisscross pattern of bright and dark lines that resemble cracks in ice floes in Earth's polar oceans.

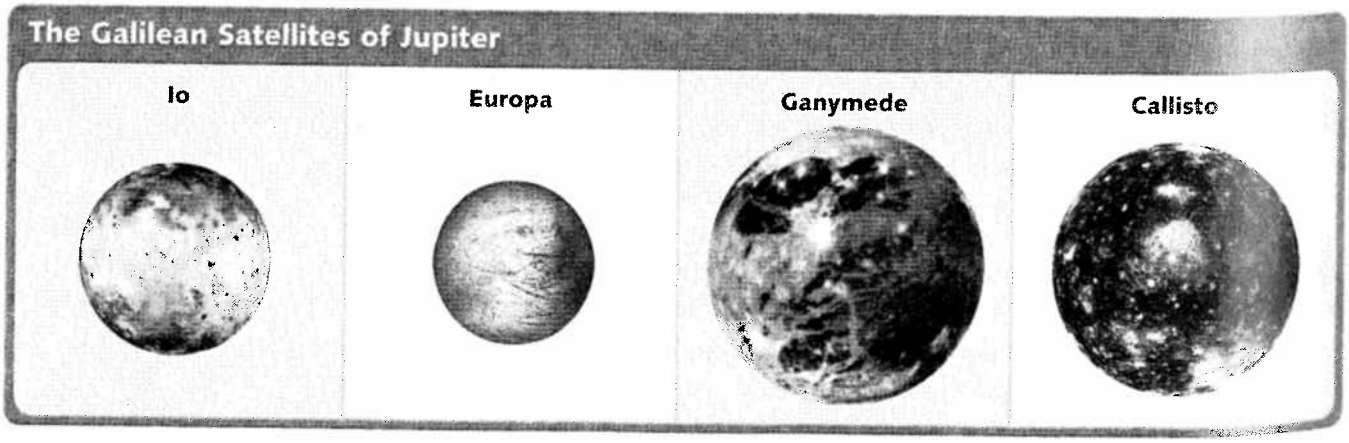
High-resolution photographs and magnetic-field data from the *Galileo* mission provide evidence that a liquid ocean 100 kilometers deep may exist below Europa's surface. If so, it is possible that life forms may have developed there, perhaps getting their energy from subsurface volcanic vents like those on Earth's ocean floor.

Ganymede, next in order from Jupiter, is the largest moon in the solar system. With a diameter of 5268 kilometers, it is larger than Pluto and Mercury, and about three-quarters the size of Mars. If Ganymede orbited the sun rather than Jupiter, it would no doubt be classified as a planet. Ganymede's density is less than 2 g/cm^3, which indicates that it is most likely composed of a large amount of ice around a rocky core. The mantle is probably ice and silicates, and the crust is believed to be a layer of water ice. Ganymede is the only one of Jupiter's moons known to have a magnetic field. This magnetosphere probably protects it from the magnetic influence of Jupiter.

Callisto, the farthest out of the Galilean satellites, is the most heavily cratered object in the solar system and is thought to be the oldest landscape in the solar system as well. About 4800 kilometers in diameter, it is the least dense of the Galilean satellites (about 1.86 g/cm^3). The *Galileo* spacecraft detected oxygen on Callisto, probably released by sunlight striking its icy surface.

Evidence from the *Galileo* spacecraft has led scientists to believe that Callisto's internal structure does not consist of separate layers. Instead, scientists now think that the interior is a mixture of ice and rock, with a rocky core. This would make Callisto's structure different from the other Galilean satellites; scientists suspect that Callisto's distance from Jupiter has allowed it to avoid the gravitational stresses of Io, Europa, and Ganymede.

Magnetic-field data from the *Galileo* spacecraft suggest that a subsurface ocean of salty liquid water several kilometers deep may exist beneath the surfaces of Ganymede and Callisto.



Saturn's Moons

Until the Space Age, Saturn was thought to have nine moons, all discovered before 1900. Recently, new moons have been discovered through telescopes and with spacecraft. At least 31 moons orbit Saturn outside of, or within, its rings. The largest and most interesting is Titan.

Titan is the second-largest moon in the solar system. Its density is just under 2 g/cm^3, and it seems to be about half rock and half frozen water.

Titan is the only moon known to have a substantial atmosphere. Its atmospheric pressure is about 1.5 times Earth's. Like Earth, its principal gas is nitrogen, which is estimated to make up between 90 and 95 percent of the total atmosphere. Most of the remaining gas is methane, with traces of hydrogen cyanide and acetylene. Titan's surface temperature is about −180°C. This is cold enough to turn methane and other gases to liquid. The resulting droplets form a dense orange smog that hides Titan's surface.

The Moons of Uranus and Neptune

Uranus is known to have at least 27 moons. The five major moons are Titania, Oberon, Umbriel, Ariel, and Miranda. All are alike in that they lack atmospheres and have many impact craters on their surfaces. But differences between the moons are visible in *Voyager* photographs. Titania has huge, faulted valleys. Oberon's impact craters are partly flooded with dark material. Umbriel has an unusual dark surface, and Ariel's cratered surface is crisscrossed by valleys and faults. Miranda proved to be the most startling of all. Its surface is deeply scarred with V-shaped grooves and parallel ridges. Some scientists theorize that Miranda has been shattered as many as five times during its existence, and after each shattering reassembled with parts of the original surface buried and parts of the core exposed. Another theory suggests the surface features resulted from upwelling of partly melted ice.

MIRANDA, one of Uranus's large moons, shows the scars that scientists think resulted from being shattered as many as five times.

Neptune has at least 13 moons. Triton, the largest of Neptune's moons, is about four-fifths the size of Earth's moon. Triton's southern ice cap is made of methane and ammonia. Ice volcanoes of nitrogen were erupting from the surface of Triton as *Voyager 2* passed by. Triton has a very thin atmosphere.

27.3 Section Review

1. What are the moons of the inner planets?
2. What makes Titan an interesting moon?
3. **CRITICAL THINKING** Why are small moons, like Deimos, potato-shaped, while larger moons are spherical?
4. **CRITICAL THINKING** Hypothesize why the Jovian planets have so many moons. Where do you think the moons came from?
5. **BIOLOGY** Which Galilean moon is most likely to support life? Explain your reasoning.

27.4

Key Idea

The solar system contains countless smaller objects—comets, asteroids, and meteoroids—which can and have collided with Earth.

Key Vocabulary

- comet
- asteroid
- meteor
- meteorite
- meteor shower

Observe an animation of a comet's passage through the solar system. *Keycode:* ES2706

Solar-System Debris

The sun, planets, and many moons are the largest components of our solar system. However, our solar system is also made up of smaller objects. Some of these have collided with Earth in the past, leaving great scars on the surface. Collisions continue to occur today.

Comets and TNOs

Comets have been described as dirty snowballs. They are made of dust particles trapped in a mixture of frozen water, carbon dioxide, methane, and ammonia. Comets spend most of their time far out beyond Neptune's orbit, where they consist only of a solid main body called a nucleus. Vast numbers of comets orbit in the cold region of our solar system beyond Neptune called the Kuiper Belt and in the much more distant Oort Cloud. More than 70,000 large bodies over a hundred kilometers in diameter are in the Kuiper Belt along with many more smaller bodies. They are known as Trans Neptunian Objects (TNOs).

A few comets, however, move in highly elliptical orbits that take them closer to the sun. When this happens, they can become visible in Earth's night sky. When a comet moves close enough to the sun (around the orbit of Jupiter), energy from the sun heats the comet's icy surface, causing it to form a coma, a cloud of gas and dust that expands into space. At a comet's closest point to the sun, its coma can be millions of kilometers long. The solar wind pushes material from the coma far out into space, forming dramatic tails that always point more or less away from the sun and may extend for millions of kilometers. As the comet moves away from the sun back toward the outer solar system, its tails actually precede it.

The famous Halley's Comet returns to the inner solar system every 76 years. The comet is named for Edmund Halley, an 18th-century English astronomer. In studying records of comets, Halley noticed that bright comets had appeared in 1531, 1607, and 1682. He thought that these were all one comet with an orbital period of about 76 years. He correctly predicted its return sometime in 1758 or 1759. It returned again in 1835, 1910, and 1986.

HALLEY'S COMET last visited Earth in 1986. Its nucleus and tail show up clearly in this false-color photograph.

TWO TAILS The tail of Comet Hale-Bopp is split. The lower tail is made of ionized molecules. The upper tail is made of dust.

Comets

Name	Orbital Period (in years)	Perihelion Date	Perihelion Distance (AUs)	Absolute Magnitude
Encke	3.30	12-28-2003	0.340	9.8
Wilson-Harrington	4.29	03-26-2001	1.000	9.0
Wild2	6.39	09-25-2003	1.583	6.5
d'Arrest	6.51	08-01-2008	1.346	8.5
Tempel-Tuttle	32.92	02-28-1998	0.982	9.0
Halley	76.1	02-09-1986	0.587	5.5
Hale-Bopp	4000	03-31-1997	0.914	−1.0

Asteroids

Asteroids are solid, rocklike masses. Most seem to have irregular shapes, which explains why their brightness changes as they rotate. There are thousands of asteroids in the solar system, but only the two largest, Ceres and Pallas, are spherical. Ceres has a diameter of about 1000 kilometers. Most asteroids are less than 1 kilometer long. Scientists think that asteroids are material leftover from the solar system's formation.

THE ASTEROID 243 IDA, photographed by the *Galileo* probe, is about 55 kilometers across at its widest point. It has a tiny moon, just 1.5 kilometers across, named Dactyl.

Asteroids revolve around the sun in the same direction as the planets. Most asteroid orbits are nearly circular and lie between Mars and Jupiter in the asteroid belt. A few, however, have long oval orbits. Some come close to Mercury at perihelion, when they are closest to the sun. Asteroids can collide, and have collided, with Earth. Many scientists believe that an asteroid or a comet collided with Earth 65 million years ago, leading to the extinction of the dinosaurs. In 1908 a much smaller object exploded with the force of a 10-megaton nuclear detonation over Siberia, leveling trees over a vast but remote area. A similar explosion over a populated area would cause massive loss of life, and the impact of an asteroid or comet could inflict terrible damage on Earth and its life systems. Although no known asteroids or comets are currently considered at risk of striking Earth, some scientists are looking into ways to prevent collisions by diverting objects before they reach Earth.

Meteors and Meteoroids

VISUALIZATIONS
CLASSZONE.COM
Observe an animation of meteor showers.
Keycode: ES2707

A meteoroid is a rock or an icy fragment traveling in space. Meteoroids are different from asteroids only in their smaller size—from less than 100 meters in diameter down to the size of a sand grain. A **meteor,** also called a shooting star, is the light made when a meteoroid passes through Earth's atmosphere. The light is caused by friction between the rapidly moving meteoroid and the atmosphere.

On a clear, dark night about 5 to 15 meteors can be seen every hour. However, this is a small portion of all meteors. Scientists estimate that anywhere from a million to a billion meteoroids enter the atmosphere daily. Most are tiny and burn or vaporize in the air.

Sometimes, large numbers of meteors streak across the night sky within a few hours of one another. Such an event is called a **meteor shower.** A meteor shower occurs when Earth passes through debris left behind by a comet, and particles from the comet's tail plunge through the atmosphere as meteors.

Because Earth's orbit crosses the paths of comets around the same time each year, many meteor showers occur at predictable times. Meteor showers are named for the constellation from which they appear to originate; for example, the Perseid meteor shower, which happens in August, seems to come from Perseus.

Meteorites

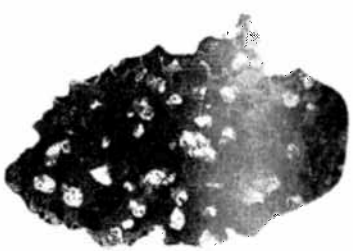
A **meteorite** is part of a large meteoroid that survives its trip through the atmosphere and strikes Earth's surface. There are three basic types of meteorites. Most, about 94 percent, are stony meteorites, which resemble Earth's dark igneous rocks. They are composed primarily of silicates.

Iron meteorites make up about 5 percent of all meteorites. They consist of large crystals made mostly of iron with a small amount of nickel. The large crystals indicate that they cooled over millions of years, suggesting that they were formed inside large asteroids that later broke apart. About 1 percent of meteorites are called stony-iron meteorites. They appear to have formed when molten silicates came into contact with molten metal.

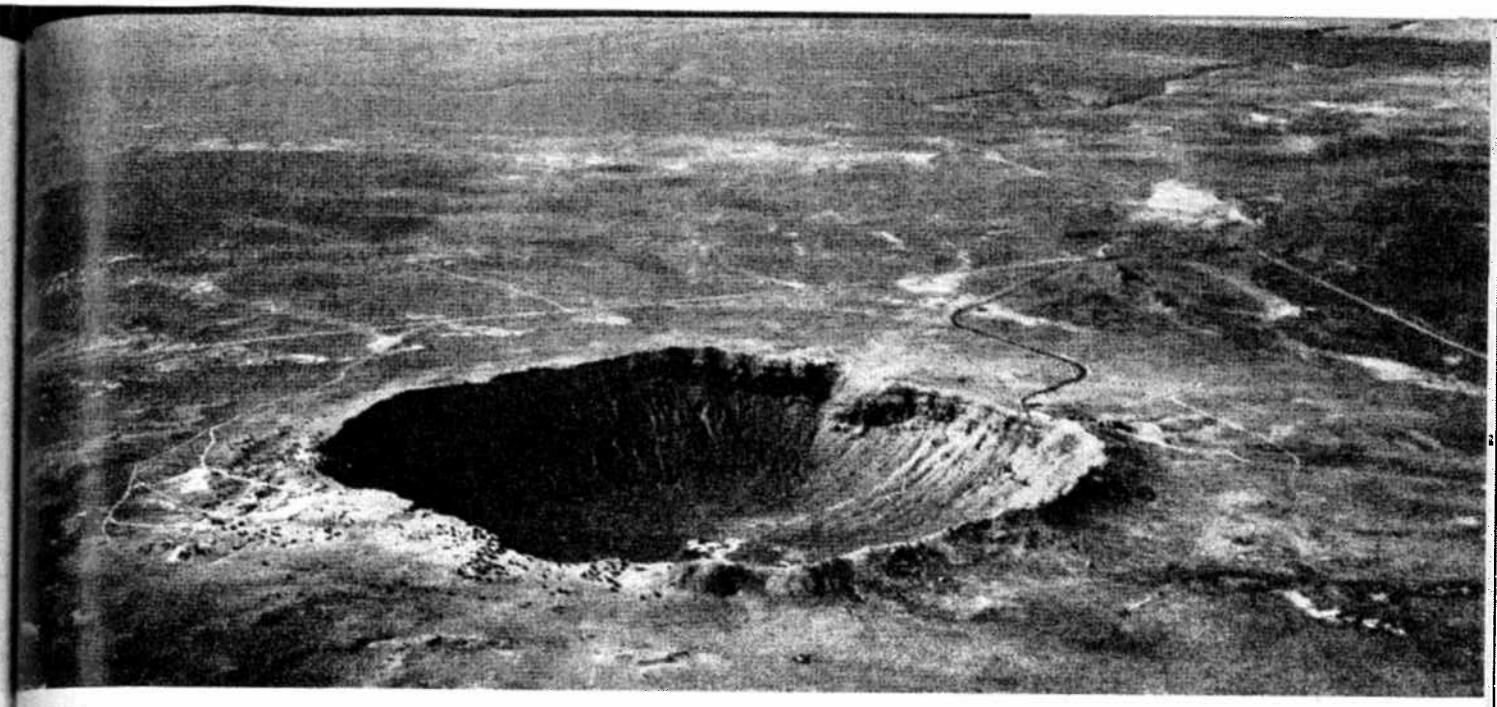
The most abundant source of meteorites is the Antarctic ice cap. Meteorites that have fallen there are exposed at the surface when wind erosion removes the ice around them. Thousands of meteorites have been recovered from Antarctica, providing an enormous increase in the supply of extraterrestrial material available for study.

STONY About 94 percent of meteorites that strike Earth are stony.

IRON meteorites account for 5 percent of meteorites that strike Earth.



STONY-IRON are the rarest meteorites, making up about 1 percent of the total.



BARRINGER METEOR CRATER in Arizona is about 1200 meters in diameter and nearly 200 meters deep.

Impact Craters

Impact craters are bowl-shaped depressions that remain after a meteor or other object strikes Earth, another planet, or a moon. Earth is not as heavily cratered as the moon, but it still bears scars of its encounters.

Impact craters are rare features on Earth; only about 150 are known to exist. One reason is that Earth's atmosphere burns up most meteoroids before they strike the surface. Another is that Earth is geologically active, and so it continually erases the marks of impacts. Earth's oldest crater, the Vredefort Crater in South Africa, is 2 billion years old. Few craters on Earth are more than half a billion years old.

One of the best-known craters is also one of the younger ones. Arizona's Barringer Meteor Crater is thought to have formed about 49,000 years ago when an iron meteorite about 45 meters in diameter struck Earth and exploded, leaving behind a crater about 1200 meters in diameter.

Impacts change Earth geologically. Very large impacts may leave rings in the surface like ripples in a pond. Other structures resulting from impacts may become reservoirs for oil and gas deposits. An impact near Sudbury, Ontario, Canada, about 1.85 billion years ago may have resulted in that area's large nickel and copper deposits.

27.4 Section Review

1. What happens to comets as they approach the sun?
2. Where are most asteroids found?
3. Explain the difference between meteoroid, meteor, and meteorite.
4. **CRITICAL THINKING** Most meteorites formed between 4.55 billion and 4.65 billion years ago, making them a little older than the oldest moon rocks. Infer why moon rocks are younger than most meteorites.
5. **MATHEMATICS** When will we next see Halley's Comet? When will Hale-Bopp next come into view?

CHAPTER 27

LAB Activity

Galilean Moons of Jupiter

Skills and Objectives

- ***Graph*** **the positions of the Galilean moons relative to Jupiter.**
- ***Analyze*** **the graph to determine patterns in the moons' motion.**
- ***Compare*** **the orbits of the four moons.**

Materials

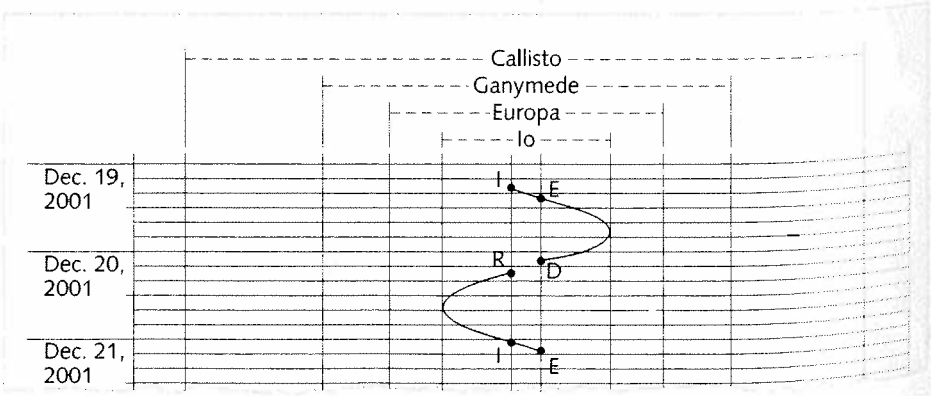
- **colored pencils**
- **Lab Sheet 27** *Galilean Moon Orbit Graph*

First discovered by Galileo in 1610, the four largest moons of Jupiter can be observed with a small telescope or binoculars. Observations of the moons have played an important role in the history of science. For example, charts predicting eclipses of Jupiter's moons helped ships at sea to calibrate their clocks. In 1676 Ole Rømer found that the eclipse charts contained systematic errors, and concluded that the reason for the errors was due to the fact that the speed of light was not infinite. Rømer then became the first scientist who attempted to calculate the speed of light.

In this activity, you will graph the positions of the Galilean moons over a period of 18 days between December 19, 2001, and January 5, 2002.

Procedure

1. Obtain a copy of the Galilean Moon Orbit Graph. Color in the space between the two central lines. This space represents the diameter of Jupiter. Fill in the key with the color you have used for Jupiter.
2. The data table gives observational data for the positions of the Galilean moons relative to Jupiter as they appear from Earth. The data include the times each moon disappears and reappears after passing in front of or behind Jupiter. An example of a complete cycle of Io's orbit is shown on the Galilean Moon Orbit Graph.
3. Use a colored pencil to plot the remaining data on the orbit graph for Io. As shown in the example, connect the events labeled E and D with a parabola to represent the portion of Io's orbit observed to the right of Jupiter. Connect the events from R to I with a parabola to represent Io's orbit to the left of Jupiter. Connect events I to E with a straight line to represent Io passing in front of Jupiter.
4. Complete the curves for the other three Galilean moons. Fill in the key with the color you have chosen for each moon.



DATA CENTER CLASSZONE.COM

Learn more about Jupiter's satellites.
Keycode: ES2709

Analysis and Conclusions

1. If you observed the moons of Jupiter with binoculars on 12/22/01 at 2 A.M. UTC, in what order would the moons and Jupiter appear from left to right? In what order would they appear on 12/30/01 at 2 A.M. UTC?

2. On 01/03/02 at 1 A.M. UTC, you observe the moons of Jupiter with a telescope, and all four moons appear to the left of Jupiter. Explain how this could happen.

3. How does the distance of a moon's orbit from Jupiter relate to the time it takes the moon to complete one orbit?

4. What is the approximate period of revolution for each moon?

5. To an observer situated above the north pole of Jupiter, do the moons revolve in a clockwise or counterclockwise direction?

6. If you wanted to observe the four moons when they are spread farthest apart and would be easily distinguishable from each other, what time would you choose from those shown on your graph? Be sure to choose a time when it is dark where you live.

Note: UTC, or Universal Coordinated Time, is a time standard used throughout the world. It is measured from the prime meridian (page 78). You may also have heard of GMT, or Greenwich Mean Time. Also measured from the prime meridian, GMT was replaced by the more accurate UTC in 1972. UTC is five hours ahead of Eastern Standard Time and eight hours ahead of Pacific Standard Time.

GALILEAN MOON ORBITAL EVENTS
I – moon begins to pass in front of Jupiter on the left side
E – moon ends passage across Jupiter
D – moon disappears behind Jupiter on right side
R – moon reappears on the left side of Jupiter

Galilean Moon Orbital Data

Date	Time (UTC) – Event (I, E, D, R)			
	Io	Europa	Ganymede	Callisto
Dec. 19, 2001	6:35 – I 8:49 – E	11:56 – I 14:40 – E		3:02 – D 5:44 – R
Dec. 20, 2001	3:33 – D 6:08 – R			
Dec. 21, 2001	1:01 – I 3:15 – E 22:02 – D	5:35 – D 14:40 – R	16:21 – D 5:44 – R	
Dec. 22, 2001	0:33 – R 19:26 – I 21:41 – E			
Dec. 23 2001	16:31 – D 18:59 – R	1:03 – I 3:52 – E		
Dec. 24, 2001	13:52 – I 15:55 – E	18:52 – D 22:02 – R		
Dec. 25, 2001	10:59 – D 13:25 – R		7:01 – I 10:03 – E	
Dec. 26, 2001	8:18 – I 10:33 – E	14:10 – I 16:58 – E		
Dec. 27, 2001	5:28 – D 7:51 – R			
Dec. 28, 2001	2:44 – I 4:58 – E 23:57 – D	8:10 – D 11:08 – R	20:20 – D 23:44 – R	11:52 – I 14:31 – E
Dec. 29, 2001	2:17 – R 21:10 – I 23:21 – E			
Dec. 30, 2001	18:25 – D 20:43 – R	3:18 – I 6:06 – E		
Dec. 31 2001	15:35 – I 17:50 – E	21:27 – D		
Jan. 1, 2002	12:53 – D 15:09 – R	0:27 – R	10:16 – I 13:18 – E	
Jan. 2, 2002	10:01 – I 12:16 – E	16:25 – I 19:13 – E		
Jan. 3, 2002	7:19 – D 9:38 – R			
Jan. 4, 2002	4:27 – I 6:42 – E	10:35 – D 13:32 – R	23:56 – D	
Jan. 5, 2002	1:45 – D 4:07 – R 22:53 – I		3:23 – R	17:06 – D 13:18 – R

CHAPTER 27 REVIEW

Summary of Key Ideas

27.1 The planets are grouped by position as inner or outer and by properties as terrestrial or Jovian. The inner planets are Mercury, Venus, Earth, and Mars. All have rocky crusts, dense mantle layers, and very dense cores.

27.2 The Jovian planets are large, consist mostly of gases, and are surrounded by ring systems and many moons. They are Jupiter, Saturn, Uranus, and Neptune. Pluto is too small to be a Jovian planet and not dense enough to be a terrestrial planet.

27.3 A planetary satellite or moon is a smaller body that revolves around a planet. Except for Venus and Mercury, each planet has at least one satellite.

27.4 The solar system also includes debris such as comets, asteroids, and meteoroids.

KEY VOCABULARY

asteroid (p. 603)
comet (p. 602)
inner planets (p. 588)
meteor (p. 604)
meteorite (p. 604)
meteor shower (p. 604)
outer planets (p. 588)

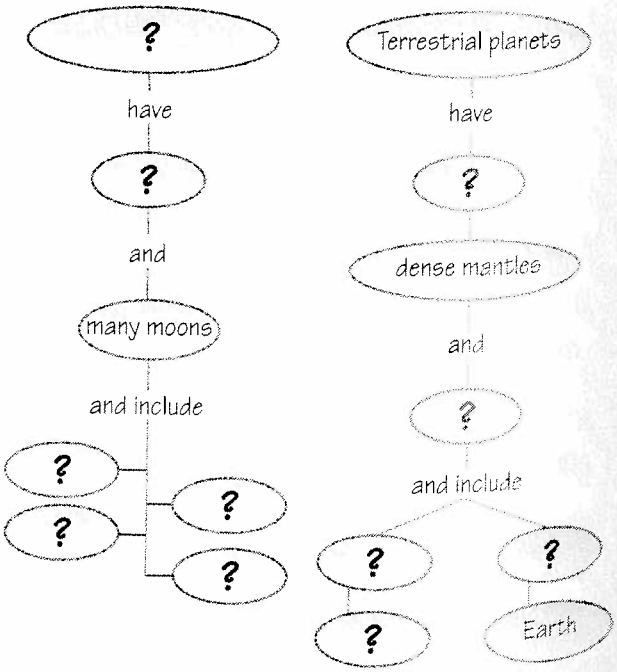
Vocabulary Review

Choose the best answer. Write the letter of the best answer on another sheet of paper.

1. Which is not a terrestrial planet?
   (a) Mars (b) Mercury (c) Saturn (d) Venus
2. A planet that has no atmosphere because of its high temperature and low gravity is
   (a) Mars (b) Pluto (c) Venus (d) Mercury
3. A planet that can be seen only as a morning star or as an evening star is
   (a) Jupiter (b) Uranus (c) Venus (d) Mars
4. Which planet has polar caps of frozen carbon dioxide? (a) Pluto (b) Mars (c) Venus (d) Jupiter
5. The Jovian planets do NOT have (a) rocky surfaces (b) moons (c) rings (d) magnetic fields

Concept Review

6. Describe the qualities the inner planets share.
7. How do comets, meteoroids, and asteroids differ?
8. Why is Pluto, one of the outer planets, not considered a Jovian planet?
9. Name a planet that does not have a moon.
10. **Graphic Organizer** Copy and complete the concept map below.



Critical Thinking

11. **Infer** Two astronomers with telescopes, one on Venus and one on Mars, are observing Earth. Who would have an easier time and why?

12. **Apply** How many complete orbits has Earth made in your lifetime? How many orbits has Mars made in your lifetime?

13. **Interpret** Neptune was discovered in 1846. Since then, a complete orbit of the sun by Neptune has not yet been observed. Why?

14. **Deduce** Phobos revolves around Mars from west to east faster than Mars rotates on its axis from west to east. Viewed from Mars, in what direction does Phobos rise and set?

15. **Hypothesize** The orbits of Neptune and Pluto cross periodically. Write an hypothesis describing whether or not you think it is likely that Neptune and Pluto could ever collide.

Internet Extension

INVESTIGATIONS
CLASSZONE.COM

What Processes Shape Planetary Surfaces? Analyze images of planetary features to compare them with features on Earth.

Keycode: ES2708

Writing About the Earth System

SCIENCE NOTEBOOK On what planet do you think scientists should concentrate their research efforts? What do you think such exploration will mean for Earth? Formulate a persuasive argument for your choice and write it in your Science Notebook.

Interpreting Graphs

The straight lines on the graph show the speed (in km/s) needed by several gas molecules to escape a planet relative to the absolute, or kelvin (K), temperature of that planet's atmosphere. Points representing the planets are also on the graph.

16. If the escape speed of a gas from a planet's atmosphere is directly related to the mass of the planet, according to the graph, which planet has the greatest mass? Is this planet the largest?

17. According to the graph, which planet has the least mass? Is this planet the smallest?

18. Using the graph, identify two pairs of planets that must have nearly the same mass because gases can escape from their atmospheres at nearly the same speeds.

19. According to the graph, which two planets have no atmosphere? A gas is not held by a planet if the line for that gas is above the point for the planet.

20. Which planets have both hydrogen and helium in their atmospheres?

21. According to the graph, how does the atmosphere of Earth differ from that of Mars?