Section 28.2

Objectives

- **Compare** the characteristics of the inner planets.
- **Survey** some of the space probes used to explore the solar system.
- **Explain** the differences among the terrestrial planets.

Review Vocabulary

albedo: the amount of sunlight that reflects from the surface

New Vocabulary

terrestrial planet
scarp

The Inner Planets

MAIN Idea Mercury, Venus, Earth, and Mars have high densities and rocky surfaces.

Real-World Reading Link Just as in a family in which brothers and sisters share a strong resemblance, the inner planets share many characteristics.

Terrestrial Planets

The four inner planets are called **terrestrial planets** because they are similar in density to Earth and have solid, rocky surfaces. Their average densities, obtained by dividing the mass of a planet by its volume, range from about 3.5 to just over 5.5 g/cm^3. Average density is an important indicator of internal conditions, and densities in this range indicate that the interiors of these planets are compressed.

Mercury

Mercury is the planet closest to the Sun, and for this reason it is difficult to see from Earth. During the day it is lost in the Sun's light and it is more easily seen at sunset and sunrise. Mercury is about one-third the size of Earth and has a smaller mass. Mercury has no moons. Radio observations in the 1960s revealed that Mercury has a slow spin of 1407.6 hours. In one orbit around the Sun, Mercury rotates one and one-half times, as shown in **Figure 28.10.** As Mercury spins, the side facing the Sun at the beginning of the orbit faces away from the Sun at the end of the orbit. This means that two complete Mercury years equal three complete Mercury days.

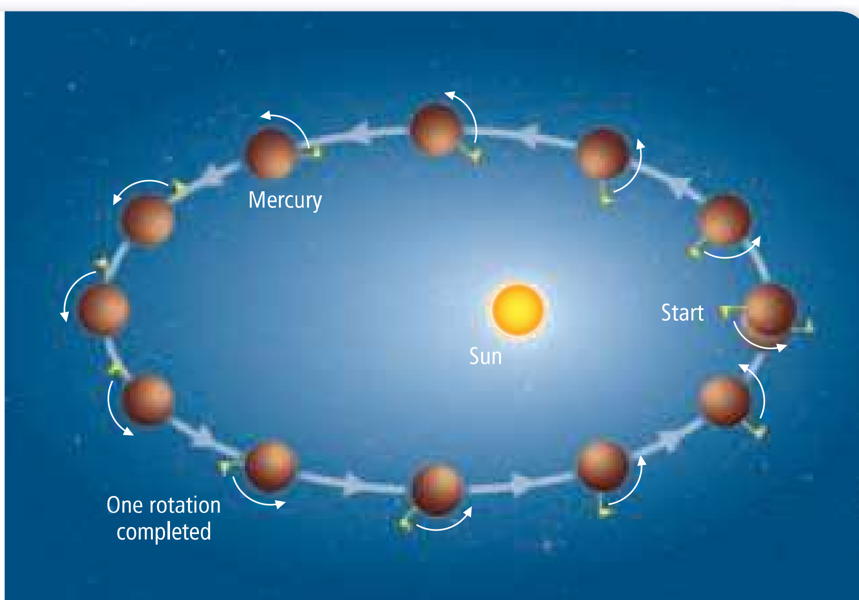


Figure 28.10 Because of Mercury's odd rotation, its day lasts for two-thirds of its year.
Compare *Mercury's orbital motion with that of Earth's Moon.*

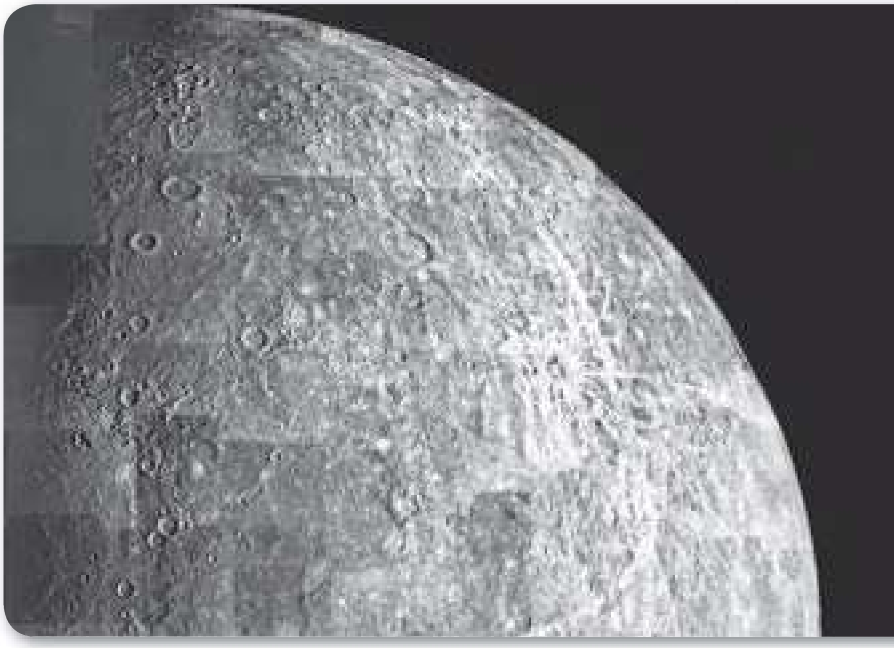


Figure 28.11 This mosaic of Mercury's heavily cratered surface was made by *Mariner 10.* Craters range in size from 100 to 1300 km in diameter.

Atmosphere Unlike Earth and the other planets, Mercury's atmosphere is constantly being replenished by the solar wind. What little atmosphere does exist is composed primarily of oxygen and sodium atoms deposited by the Sun. The daytime surface temperature on Mercury is 700 K (427°C), while temperatures at night fall to 100 K (−173°C). This is the largest day-night temperature difference among the planets.

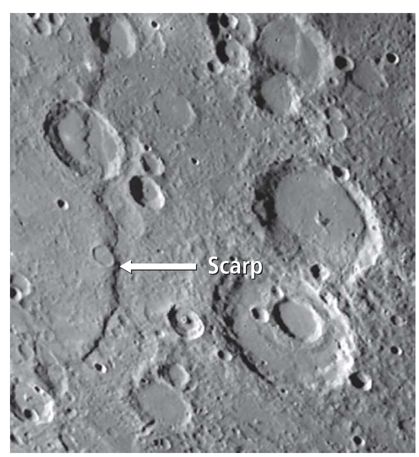
Surface Most knowledge about Mercury is based on the radio observations from Earth, and images from U.S. space probe *Mariner 10,* which passed close to Mercury three times in 1974 and 1975. Images from *Mariner 10* show that Mercury's surface, like that of the Moon, is covered with craters and plains, as shown in **Figure 28.11.** The plains on Mercury's surface are smooth and relatively crater free. Scientists think that the plains formed from lava flows that covered cratered terrain, much like the maria formed on the Moon. The surface gravity of Mercury is much greater than that of the Moon, resulting in smaller crater diameters and shorter lengths of ejecta.

Mercury has a planetwide system of cliffs called **scarps,** such as the one shown in **Figure 28.12.** Though similar to those on Earth, Mercury's scarps are much higher. Scientists hypothesize that the scarps developed as Mercury's crust shrank and fractured early in the planet's geologic history. Scientists will learn more about the surface of Mercury with the arrival of the Japanese-European *Messenger* mission in 2011.

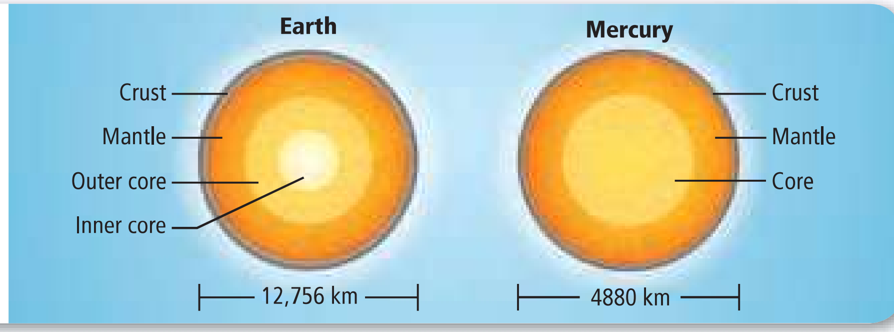
Reading Check **Compare** the surfaces of the Moon and Mercury.

Interior Without seismic data, scientists have no way to analyze the interior of Mercury. However, its high density suggests that Mercury has a large nickel-iron core. Mercury's small magnetic field indicates that some of its core is molten.

Figure 28.12 Discovery, the largest scarp on Mercury, is 550 km long and 1.5 km high.



■ **Figure 28.13** The structure of Mercury's interior, which contains a proportionally larger core than Earth, suggests that Mercury was once much larger.



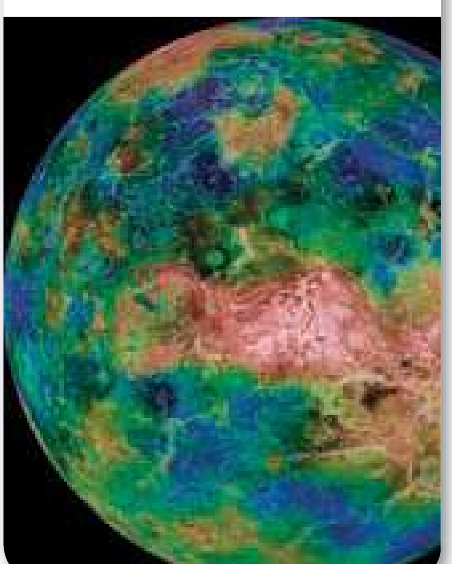
Early Mercury Mercury's small size, high density, and probable molten interior resemble what Earth might be like if its crust and mantle were removed, as shown in **Figure 28.13.** These observations suggest that Mercury was originally much larger, with a mantle and crust similar to Earth's, and that the outer layers might have been lost in a collision with another celestial body early in its history.

Venus

Venus and Mercury are the only two planets closer to the Sun than Earth. Like Mercury, Venus has no moons. Venus is the brightest planet in the sky because it is close to Earth and because its albedo is 0.75—the highest of any planet. Venus is the first bright "star" to be seen after sunset in the western sky, or the last "star" to be seen before sunrise in the morning, depending on which side of the Sun it is on. For these reasons it is often called either the evening or morning star.

Thick clouds around Venus prevent astronomers from observing the surface directly. However, astronomers learned much about Venus from spacecraft launched by the United States and the Soviet Union. Some probes landed on the surface of the planet, and others flew by. Then, the 1978 *Pioneer-Venus* and 1989 *Magellan* missions of the United States used radar to map 98 percent of the surface of Venus. A view of the surface was obtained using a type of radar imaging and combining images from *Magellan* spacecraft with those produced by the radio telescope in Arecibo, Puerto Rico. This view, shown in **Figure 28.14,** uses false colors to outline the major landmasses. In 2006, a European space probe, called *Venus Express*, went into orbit around Venus. Its mission was to gather atmospheric data for about one and one-half years.

■ **Figure 28.14** Radar imaging revealed the surface of Venus. Highlands are shown in red, and valleys are shown in blue. Large highland regions are like continents on Earth.
Infer ***What do green areas represent?***



Retrograde rotation Radar measurements show that Venus rotates slowly—a day on Venus is equivalent to 243 Earth days. Also, Venus rotates clockwise, unlike most planets that spin counterclockwise. This backward spin, called retrograde rotation, means that an observer on Venus would see the Sun rise in the west and set in the east. Astronomers theorize that this retrograde rotation might be the result of a collision between Venus and another body early in the solar system's history.

NASA/Roger Ressmeyer/CORBIS

Atmosphere Venus is the planet most similar to Earth in physical properties, such as diameter, mass, and density, but its surface conditions and atmosphere are vastly different from those on Earth. The atmospheric pressure on Venus is 92 atmospheres (atm), compared to 1 atm at sea level on Earth. If you were on Venus, the pressure of the atmosphere would make you feel like you were under 915 m of water.

The atmosphere of Venus is composed primarily of carbon dioxide and nitrogen, somewhat similar to Earth's atmosphere. Venus also has clouds, as shown in **Figure 28.15,** an image taken of the night side of Venus by *Venus Express*. Instead of being composed of water vapor and ice, as on Earth, clouds on Venus consist of sulfuric acid.

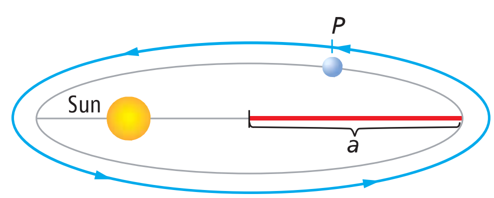
Greenhouse effect Venus also experiences a greenhouse effect similar to Earth's, but Venus's is more efficient. As you learned in Chapter 14, greenhouse gases in Earth's atmosphere trap infrared radiation and keep Earth much warmer than it would be if it had no atmosphere. The concentration of carbon dioxide is so high in Venus's atmosphere that it keeps the surface extremely hot—hot enough to melt lead. In fact, Venus is the hottest planet, with an average surface temperature of about 737 K (464°C), compared with Earth's average surface temperature of 288 K (15°C). It is so hot on the surface of Venus that no liquid water can exist.

Figure 28.15 Clouds swirl around Venus in this image taken using ultraviolet wavelengths.

PROBLEM-SOLVING LAB

Apply Kepler's Third Law

How well do the orbits of the planets conform to Kepler's third law? For the six planets closest to the Sun, Kepler observed that $P^2 = a^3$, where P is the orbital period in years and a is the semimajor axis in AU.



Analysis

1. Use this typical planet orbit diagram and the data from the *Reference Handbook* to confirm the relationship between P^2 and a^3 for each of the planets.

Think Critically

2. **Prepare** a table showing your results and how much they deviate from predicted values.
3. **Determine** which planets conform most closely to Kepler's law and which do not seem to follow it.
4. **Consider** Would Kepler have formulated this law if he had been able to study Uranus and Neptune? Explain.
5. **Predict** the orbital period of an asteroid orbiting the Sun at 2.5 AU.
6. **Solve** Find the semimajor axis of Halley's comet, which has an orbital period of 76 years.

Surface The *Magellan* orbiter used radar reflection measurements to map the surface of Venus. This revealed that Venus has a surface smoothed by volcanic lava flows and with few impact craters. The most recent volcanic activity took place about 500 mya. Unlike Earth, there is little evidence of current tectonic activity on Venus, and there is no well-defined system of crustal plates.

Interior Because the size and density of Venus are similar to Earth's, it is probable that the internal structure is similar also. Astronomers theorize that Venus has a liquid metal core that extends halfway to the surface. Despite this core, Venus has no measurable magnetic field, probably because of its slow rotation.

Earth

Earth, shown in **Figure 28.16,** has many unique properties when compared with other planets. Its distance from the Sun and its nearly circular orbit allow water to exist on its surface in all three states—solid, liquid, and gas. Liquid water is required for life, and Earth's abundance of water has been important for the development and existence of life on Earth. In addition, Earth's mild greenhouse effect and moderately dense atmosphere of nitrogen and oxygen provide conditions suitable for life.

Earth is the most dense and the most tectonically active of the terrestrial planets. It is the only planet where plate tectonics occurs. Unlike the other terrestrial planets, Earth has a moon, probably acquired by an impact, as you learned in the Chapter 27.

Mars

Mars is often referred to as the red planet because of its reddish surface color, as shown in **Figure 28.16.** Mars is smaller and less dense than Earth and has two irregularly shaped moons—Phobos and Deimos. Mars has been the target of a lot of recent exploration —Mars *Odyssey* and *Global Surveyor* in 2001, *Exploration Rovers*, *Reconnaissance Orbiter*, and *Mars Express* in 2003.

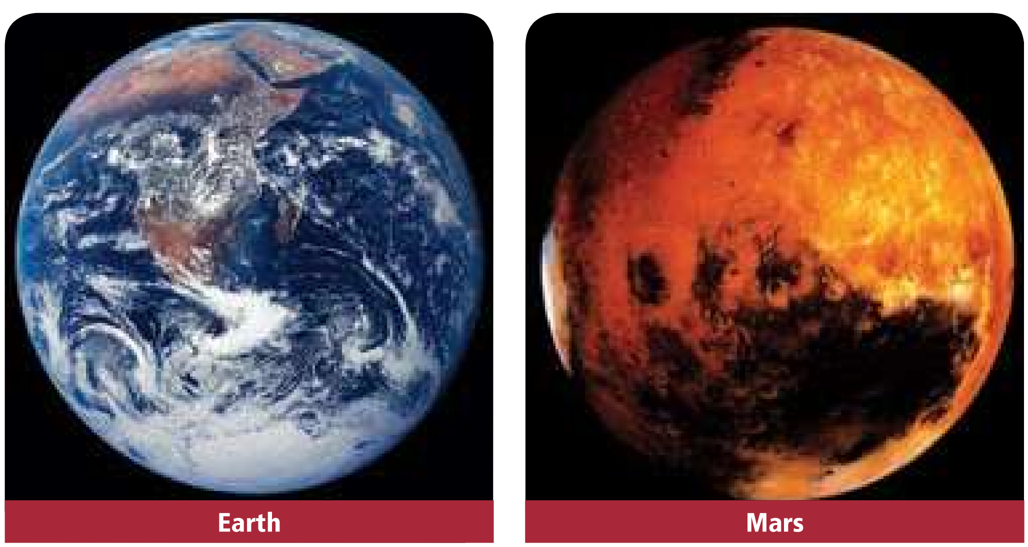


Figure 28.16 Earth's blue seas and white clouds contrast sharply with the reddish, barren Mars.

Olympus Mons volcano

Gusev crater

■ **Figure 28.17** Orbital probes and landers have provided photographic details of the Martian features and surface, such as Olympus Mons and Gusev crater.

Atmosphere Both Mars and Venus have atmospheres of similar composition. The density and pressure of the atmosphere on Mars are much lower; therefore Mars does not have a strong greenhouse effect like Venus does. Although the atmosphere is thin, it is turbulent—there is constant wind, and dust storms can last for weeks at a time.

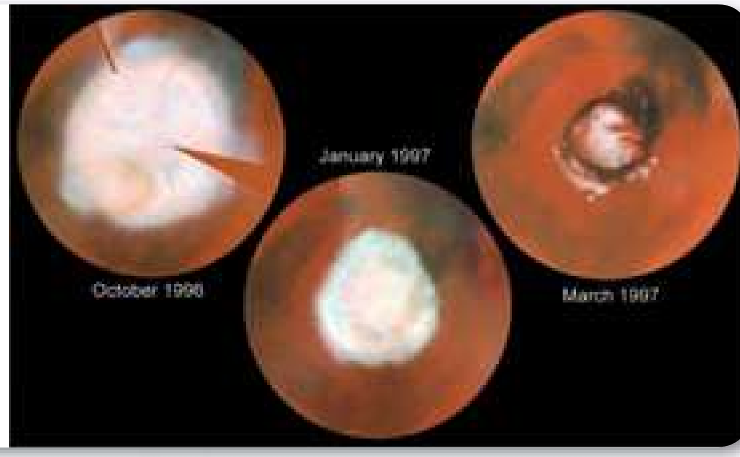
Surface The southern and northern hemispheres of Mars vary greatly. The southern hemisphere is a heavily cratered, highland region resembling the highlands of the Moon, as shown in **Figure 28.17.** The northern hemisphere has sparsely cratered plains. Scientists theorize that great lava flows covered the once-cratered terrain of the northern hemisphere. Four gigantic shield volcanoes are located near the equator, near a region called the Tharsis Plateau. The largest volcano on Mars is Olympus Mons. The base of Olympus Mons is larger than the state of Colorado, and the volcano rises 3 times higher than Mount Everest in the Himalayas.

Tectonics An enormous canyon, Valles Marineris, shown in **Figure 28.18,** lies on the Martian equator, splitting the Tharsis Plateau. This canyon is 4000 km long—almost 10 times the length of the Grand Canyon on Earth and more than 3 times its depth. It probably formed as a fracture during a period of tectonic activity 3 bya, when Tharsis Plateau was uplifted. The gigantic volcanoes were caused during the same period by upwelling of magma at a hot spot, much like the Hawaiian Island chain was formed. However, with no plate movement on Mars, magma accumulated in one area.

Erosional features Other Martian surface features include dried river and lake beds, outflow channels, and runoff channels. These erosional features suggest that liquid water once existed on the surface of Mars. Astronomers think that the atmosphere was once much warmer, thicker, and richer in carbon dioxide, allowing liquid water to flow on Mars. Although there is a relatively small amount of ice at the poles, astronomers continue to search for water at other locations on the Martian surface.

■ **Figure 28.18** Valles Marineris is a 4000-km-long canyon on Mars.

■ **Figure 28.19** These images of Mars's northern ice cap were taken three months apart by the *Hubble Space Telescope* in 1997.
Interpret *What do these images indicate about the orientation of Mars's axis?*



Ice caps Ice caps cover both poles on Mars. The caps grow and shrink with the seasons. Martian seasons are caused by a combination of a tilted axis and a slightly eccentric orbit. Both caps are made of carbon dioxide ice, sometimes called dry ice. Water ice lies beneath the carbon dioxide ice in the northern cap, shown in **Figure 28.19,** and is exposed during the northern hemisphere's summer when the carbon dioxide ice evaporates. There might also be water ice beneath the southern cap, but the carbon dioxide ice does not completely evaporate to expose it.

Interior The internal structure of Mars remains unknown. Astronomers hypothesize that there is a core of iron, nickel, and possibly sulfur that extends somewhere between 1200 km and 2400 km from the center of the planet. Because Mars has no magnetic field, astronomers think that the core is probably solid. Above the solid core is a mantle. There is no evidence of current tectonic activity or tectonic plates on the surface of the crust.

Section 28.2 Assessment

Section Summary

- Mercury is heavily cratered and has high cliffs. It has a hot surface and no real atmosphere.
- Venus has clouds containing sulfuric acid and an atmosphere of carbon dioxide that produces a strong greenhouse effect.
- Earth is the only planet that has all three forms of water on its surface.
- Mars has a thin atmosphere. Surface features include four volcanoes and channels that suggest that liquid water once existed on the surface.

Understand Main Ideas

1. MAIN Idea **Identify** the reason that the inner planets are called terrestrial planets.
2. **Summarize** the characteristics of each of the terrestrial planets.
3. **Compare** the average surface temperatures of Earth and Venus, and describe what causes them.
4. **Describe** the evidence that indicates there was once tectonic activity on Mercury, Venus, and Mars.

Think Critically

5. **Consider** what the inner planets would be like if impacts had not shaped their formation and evolution.

MATH in Earth Science

6. Using the *Reference Handbook,* create a graph showing the distance from the Sun for each terrestrial planet on the *x*-axis and their orbital periods in Earth days on the *y*-axis. For more help, refer to the *Skillbuilder Handbook.*

Earth Science Online Self-Check Quiz glencoe.com

Section 28.3

The Outer Planets

MAIN Idea Jupiter, Saturn, Uranus, and Neptune have large masses, low densities, and many moons and rings.

Real-World Reading Link Just as the inner planets resemble a family that shares many physical characteristics, the outer planets also show strong family resemblances.

Objectives

- **Compare and contrast** the gas giant planets.
- **Identify** the major moons.
- **Explain** the formation of moons and rings.
- **Compare** the composition of the gas planets to the composition of the Sun.

Review Vocabulary

asteroid: metallic or silicate-rich objects that orbit the Sun in a belt between Mars and Jupiter

New Vocabulary

gas giant planet
liquid metallic hydrogen
belt
zone

The Gas Giant Planets

Jupiter, Saturn, Uranus, and Neptune are known as the gas giants. The **gas giant planets** are all very large, ranging from 15 to more than 300 times the mass of Earth, and from about 4 to more than 10 times Earth's diameter. Their interiors are either gases or liquids, and they might have small, solid cores. They are made primarily of lightweight elements such as hydrogen, helium, carbon, nitrogen, and oxygen, and they are very cold at their surfaces. The gas giants have many satellites as well as ring systems.

Jupiter

Jupiter is the largest planet, with a diameter one-tenth that of the Sun and 11 times larger than Earth's. Jupiter's mass makes up 70 percent of all planetary matter in the solar system. Jupiter appears bright because its albedo is 0.52. Telescopic views of Jupiter show a banded appearance, as a result of flow patterns in its atmosphere. Nestled among Jupiter's cloud bands is the Great Red Spot, an atmospheric storm that has raged for more than 300 years. This is shown in **Figure 28.20.**

Rings The *Galileo* spacecraft observed Jupiter and its moons during a 5-year mission in the 1990s. It revealed two faint rings around the planet in addition to a 6400-km-wide ring around Jupiter that had been discovered by *Voyager 1.* A portion of Jupiter's faint ring system is also shown in **Figure 28.20.**

Figure 28.20 Jupiter's cloud bands contain the Great Red Spot. The planet is circled by three faint rings that are probably composed of dust particles.


Jupiter's cloud bands


Jupiter's rings

Atmosphere and interior Jupiter has a density of 1.326 g/m^3, which is low for its size, because it is composed mostly of hydrogen and helium in gaseous or liquid form. Below the liquid hydrogen is a layer of **liquid metallic hydrogen,** a form of hydrogen that has properties of both a liquid and a metal, which can exist only under conditions of very high pressure. Electric currents exist within the layer of liquid metallic hydrogen and generate Jupiter's magnetic field. Models suggest that Jupiter might have an Earth-sized solid core containing heavier elements.

Rotation Jupiter rotates very rapidly for its size; it spins once on its axis in a little less than 10 hours, giving it the shortest day in the solar system. This rapid rotation distorts the shape of the planet so that the diameter through its equatorial plane is 7 percent larger than the diameter through its poles. Jupiter's rapid rotation causes its clouds to flow rapidly as well, in bands of alternating dark and light colors called belts and zones. **Belts** are low, warm, dark-colored clouds that sink, and **zones** are high, cool, light-colored clouds that rise. These are similar to cloud patterns in Earth's atmosphere caused by Earth's rotation.

Moons Jupiter has more than 60 moons, most of which are extremely small. Jupiter's four largest moons, Io, Europa, Ganymede, and Callisto, are called Galilean satellites after their discoverer. Three of them are bigger than Earth's Moon, and all four are composed of ice and rock. The ice content is lower in Io and Europa, which are shown in **Figure 28.21,** because they have been squeezed and heated by Jupiter's gravitational force more than the outer Galilean moons. In fact, Io is almost completely molten inside and undergoes constant volcanic eruptions. Gravitational heating has melted Europa's ice in the past, and astronomers hypothesize that it still has a subsurface ocean of liquid water. Cracks and water channels mark Europa's icy surface.

Reading Check **Explain** why scientists think that Europa has an ocean of liquid water beneath its surface.

Jupiter's smaller moons were discovered by a series of space probes beginning with *Pioneer 10* and *Pioneer 11* in the 1970s followed by *Voyager 1* and *Voyager 2* that also detected Jupiter's rings. Most of the information on Jupiter and its moons came from the *Galileo* space probe that arrived at Jupiter in 1995. Jupiter's four small, inner moons are thought to be the source of Jupiter's rings. Scientists think that the rings are produced as meteoroids strike these moons and release fine dust into Jupiter's orbit.

Gravity assist A technique first used to help propel *Mariner 10* to Venus and Mars was to use the Sun's gravity to boost the speed of the satellite. Today it is common for satellites to use a planet's gravity to help propel them deeper into space. Jupiter is the most massive planet, and so any satellite passing deeper into space than Jupiter uses its gravity to give it an assist. Recent flybys on their way to Saturn and Pluto by the *Cassini* and *New Horizons* missions used that assist.

Figure 28.21 Jupiter's gravity heats Europa and Io, causing some visible effects: volcanic eruptions on Io and melting and refreezing of Europa's icy surface causing it to be crisscrossed by cracks and water channels.


Io


Europa

Saturn

Saturn, shown in **Figure 28.22,** is the second-largest planet in the solar system. Five space probes have visited Saturn, including *Pioneer 10, Pioneer 11,* and *Voyagers 1* and *2.* In 2004, the United States' *Cassini* mission arrived at Saturn and began to orbit the planet.

Atmosphere and interior Saturn is slightly smaller than Jupiter and its average density is lower than that of water. Like Jupiter, Saturn rotates rapidly for its size and has a layered cloud system. Saturn's atmosphere is mostly hydrogen and helium with ammonia ice near the cloud tops. The internal structure of Saturn is probably similar to Jupiter's—fluid throughout, except for a small, solid core. Saturn's magnetic field is 1000 times stronger than Earth's and is aligned with its rotational axis. This is highly unusual among the planets.

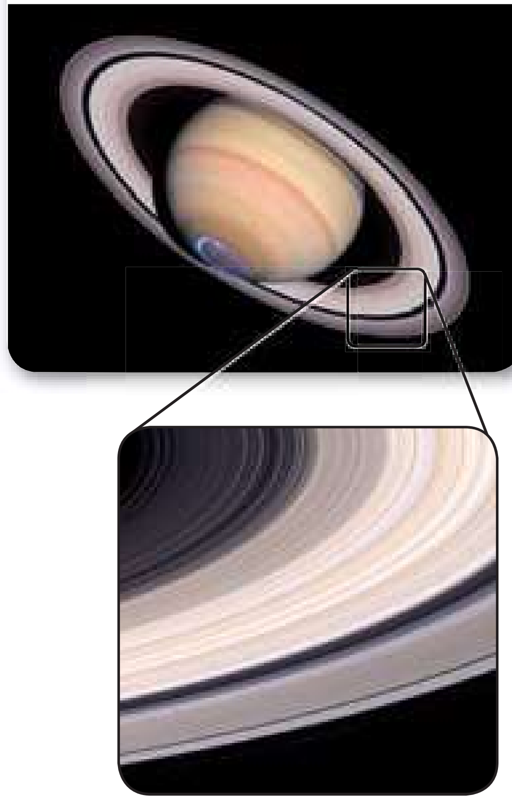
Rings Saturn's most striking feature is its rings, which are shown in **Figure 28.22.** Saturn's rings are much broader and brighter than those of the other gas giant planets. They are composed of pieces of ice that range from microscopic particles to house-sized chunks. There are seven major rings, and each ring is made up of narrower rings, called ringlets. The rings contain many open gaps.

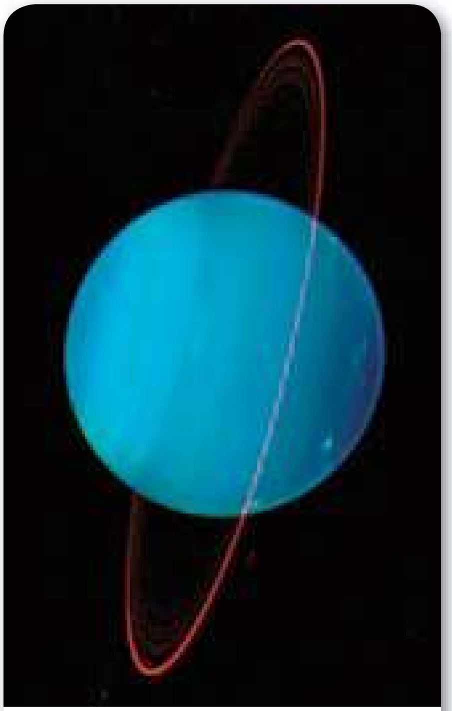
These ringlets and gaps are caused by the gravitational effects of Saturn's many moons. The rings are thin—less than 200 m thick—because rotational forces keep the orbits of all the particles confined to Saturn's equatorial plane. The ring particles have not combined to form a large satellite because Saturn's gravity prevents particles located close to the planet from sticking together. This is why the major moons of the gas giant planets are always beyond the rings.

Origin of the rings Until recently, astronomers thought that the ring particles were left over from the formation of Saturn and its moons. Now, many astronomers think it is more likely that the ring particles are debris left over from collisions of asteroids and other objects, or from moons broken apart by Saturn's gravity.

Moons Saturn has more than 45 satellites, including the giant Titan, which is larger than the planet Mercury. Titan is unique among planetary satellites because it has a dense atmosphere made of nitrogen and methane. Methane can exist as a gas, a liquid, and a solid on Titan's surface. In 2005, *Cassini* released the *Huygens* (HOY gens) probe into Titan's atmosphere. *Cassini* detected plumes of ice and water vapor ejected from Saturn's moon Enceladus, suggesting geologic activity.

Figure 28.22 Saturn's rings are made of chunks of rock and ice that can be as small as dust particles or as large as a house. A close-up view reveals ringlets and gaps.
Explain ***why the ring particles orbit Saturn in the same plane.***





■ **Figure 28.23** The blue color of Uranus is caused by methane in its atmosphere, which reflects blue light.

Uranus

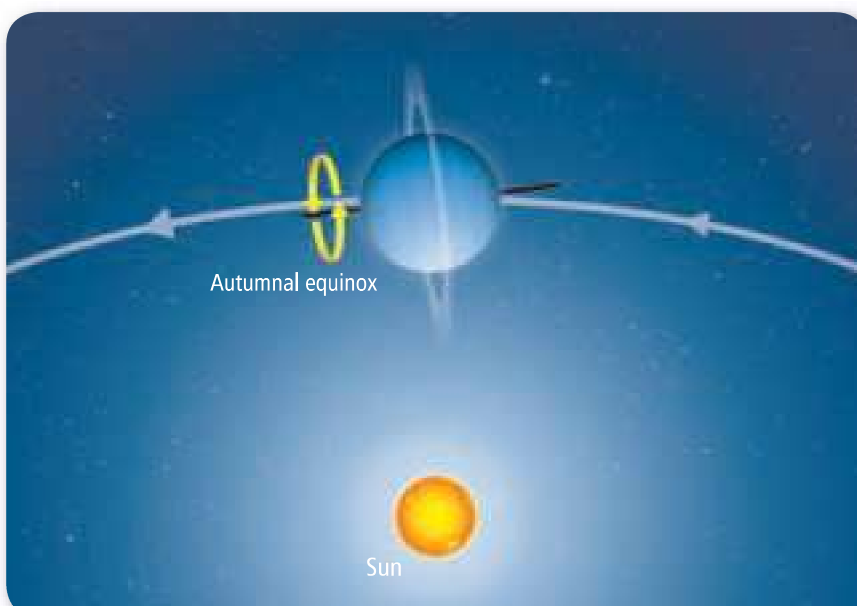
Uranus was discovered accidentally in 1781, when a bluish object was observed moving relative to the stars. In 1986, *Voyager 2* flew by Uranus and provided detailed information about the planet, including the existence of new moons and rings. Uranus's average temperature is 58 K (–215°C).

Atmosphere Uranus is 4 times larger and 15 times more massive than Earth. It has a blue, velvety appearance, shown in **Figure 28.23,** which is caused by methane gas in Uranus's atmosphere. Most of Uranus's atmosphere is composed of helium and hydrogen, which are colorless. There are few clouds, and they differ little in brightness and color from the surrounding atmosphere contributing to Uranus's featureless appearance. The internal structure of Uranus is similar to that of Jupiter and Saturn; it is completely fluid except for a small, solid core. Uranus also has a strong magnetic field.

Moons and rings Uranus has at least 27 moons and a faint ring system. Many of Uranus's rings are dark—almost black and almost invisible. They were discovered only when the brightness of a star behind the rings dimmed as Uranus moved in its orbit and the rings blocked the starlight.

Rotation The rotational axis of Uranus is tipped so far that its north pole almost lies in its orbital plane, as shown in **Figure 28.24.** Astronomers hypothesize that Uranus was knocked sideways by a massive collision with a passing object, such as a large asteroid, early in the solar system's history. Each pole on Uranus spends 42 Earth years in darkness and 42 Earth years in sunlight due to this tilt.

■ **Figure 28.24** The axis or rotation of Uranus is tipped 98 degrees. This view shows its position at an equinox.
Draw ***a diagram showing its position at the other equinox and solstices.***



Neptune

The existence of Neptune was predicted before it was discovered, based on small deviations in the motion of Uranus and the application of Newton's universal law of gravitation. In 1846, Neptune was discovered where astronomers had predicted it to be. Few details can be observed on Neptune with an Earth-based telescope, but *Voyager 2* flew past Neptune in 1989 and took the image of its cloud-streaked atmosphere, shown in **Figure 28.25.** Neptune is the last of the gas giant planets and orbits the Sun almost 4.5 billion km away.

Atmosphere Neptune is slightly smaller and denser than Uranus, but its radius is about 4 times as large as Earth's. Other similarities between Neptune and Uranus include their bluish color caused by methane in the atmosphere, their atmospheric compositions, temperatures, magnetic fields, interiors, and particle belts or rings. Unlike Uranus, however, Neptune has distinctive clouds and atmospheric belts and zones similar to those of Jupiter and Saturn. In fact, Neptune once had a persistent storm, the Great Dark Spot, similar to Jupiter's Great Red Spot, but the storm disappeared in 1994.

Moons and rings Neptune has 13 moons, the largest of which is Triton. Triton has a retrograde orbit, which means that it orbits backward, unlike other large satellites in the solar system. Triton, as shown in **Figure 28.25,** has a thin atmosphere and nitrogen geysers**.** The geysers are caused by nitrogen gas below Triton's south polar ice, which expands and erupts when heated by the Sun. Neptune's six rings are composed of microscopic dust particles, which do not reflect light well. Therefore, Neptune's rings are not as visible from Earth as Saturn's rings.

Neptune cloud streaks

Triton

Figure 28.25 *Voyager 2* took the image of Neptune above showing its cloud streaks, as well as this close-up view of Neptune's largest moon, Triton. Dark streaks indicate the sites of nitrogen geysers.

Section 28.3 Assessment

Section Summary

- The gas giant planets are composed mostly of hydrogen and helium.
- The gas giant planets have ring systems and many moons.
- Some moons of Jupiter and Saturn have water and experience volcanic activity.
- All four gas giant planets have been visited by space probes.

Understand Main Ideas

1. MAIN Idea **Create** a table that lists the gas giant planets and their characteristics.
2. **Compare** the composition of the gas giant planets to the Sun.
3. **Compare** Earth's Moon with the moons of the gas giant planets.

Think Critically

4. **Evaluate** Where do you think are the most likely sites on which to find extraterrestrial life? Explain.

WRITING in Earth Science

5. Research and describe one of the *Voyager* missions to interstellar space.

Section 28.4

Objectives

- **Distinguish** between planets and dwarf planets.
- **Identify** the oldest members of the solar system.
- **Describe** meteoroids, meteors, and meteorites.
- **Determine** the structure and behavior of comets.

Review Vocabulary

smog: air polluted with hydrocarbons and nitrogen oxides

New Vocabulary

dwarf planet
meteoroid
meteor
meteorite
Kuiper belt
comet
meteor shower

Figure 28.26 Imaged from the *Hubble Space Telescope,* the newly described dwarf planet, Ceres, is the largest body in the asteroid belt.

Other Solar System Objects

MAIN Idea Rocks, dust, and ice compose the remaining 2 percent of the solar system.

Real-World Reading Link The radio might have been your favorite source of music until digital music players became available. Similarly, improvements in technology lead to a change in Pluto's rank as a planet when astronomers discovered many more objects that had similar characteristics to Pluto.

Dwarf Planets

In the early 2000s, astronomers began to detect large objects in the region of the planet Pluto, about 40 AU from the Sun, called the Kuiper belt. Then in 2003, one object, now known as Eris, was discovered that appeared to be the same size, or larger, than Pluto. At this time, the scientific community began to take a closer look at the planetary status of Pluto and other solar system objects.

Ceres In 1801, Giuseppe Piazzi discovered a large object in orbit between Mars and Jupiter. Scientists had predicted that there was a planet somewhere in that region, and it seemed that this discovery was it. However, Ceres, shown in **Figure 28.26,** was extremely small for a planet. In the following century, hundreds—now hundreds of thousands—of other objects were discovered in the same region. Therefore, Ceres was no longer thought of as a planet, but as the largest of the asteroids in what would be called the asteroid belt.

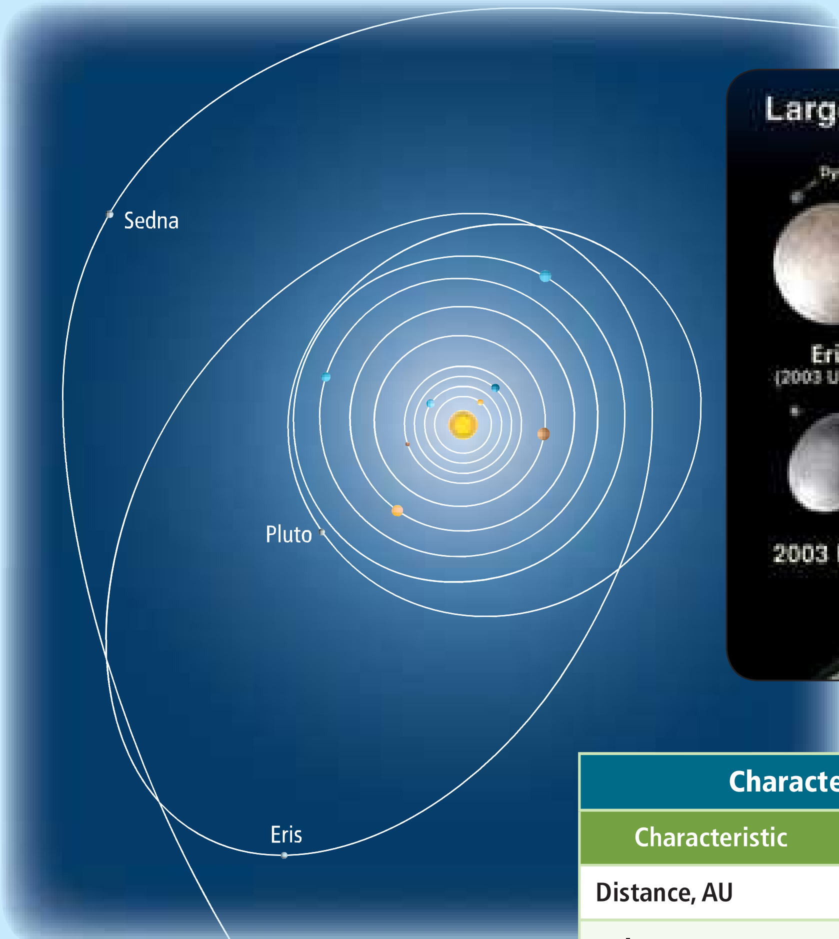
Pluto Since its discovery by Clyde Tombaugh in 1930, Pluto has been an unusual planet. It is not a terrestrial or gas planet; it is made of rock and ice. It does not have a circular orbit; its orbit is long, elliptical, and overlaps the orbit of Neptune. And it is smaller than Earth's Moon. It is one of many similar objects that exist outside of the orbit of Neptune. It has three moons, two of which orbit at widely odd angles from the plane of the ecliptic.

How many others? With the discovery of objects close to and larger than Pluto's size, the International Astronomical Union (IAU) faced a dilemma. Should Eris be named the tenth planet? Or should there be a change in the way these new objects are classified? For now, the answer is change. Pluto, Eris, and Ceres have been placed into a new classification of objects in space called dwarf planets. The IAU has defined a **dwarf planet** as an object that, due to its own gravity, is spherical in shape, orbits the Sun, is not a satellite, and has not cleared the area of its orbit of smaller debris. Currently the IAU has limited this classification to Pluto, Eris, and Ceres, but there are at least 12 other objects whose classifications are undecided, some of which are shown in **Figure 28.27.**

Visualizing the Kuiper Belt

NATIONAL GEOGRAPHIC

Figure 28.27 Recent findings of objects beyond Pluto, in a vast disk called the Kuiper belt, have forced scientists to rethink what features define a planet.
(Note: *Buffy (XR190) is a nickname used by its discoverer. EL61 is an official number assigned to an unnamed body.*)



Characteristics of Kuiper Belt Objects					
Characteristic	**Pluto**	**Sedna**	**Eris**	**EL61**	**Buffy**
Distance, AU	30	67	97	52	58
Color	Red	Red	White	Bluish	?
Relative size	1	0.75	1.05	0.75	3
Moons	3	?	1	2	?
Orbital period, years	248	10,500	560	285	440
Orbital tilt, degrees	17	12	44	28	47
Orbital eccentricity	0.25	0.85	0.43	0.19	0

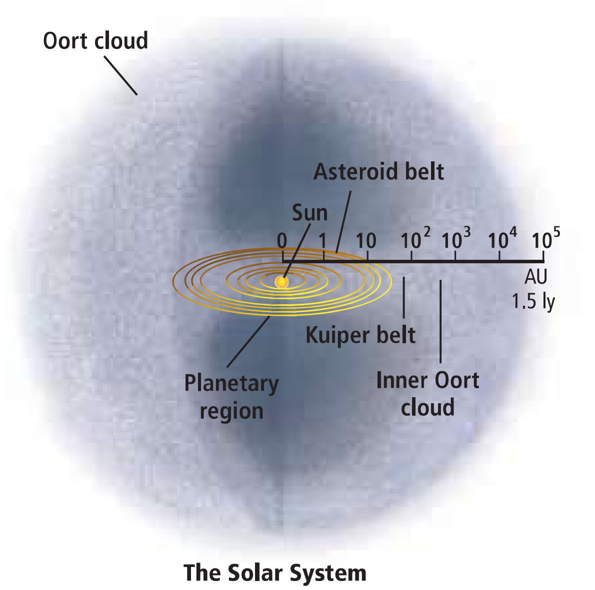
Concepts In Motion To explore more about the Kuiper belt objects, visit glencoe.com.

Earth Science Online

■ **Figure 28.28** Asteroid Ida and its tiny moon, Dactyl, are shown in this image gathered by the *Galileo* spacecraft.

NASA/Photo Researchers

■ **Figure 28.29** The Kuiper belt appears as the outermost limit of the planetary disk. The Oort cloud surrounds the Sun, echoing its solar sphere.



Small Solar System Bodies

Once the IAU defined planets and dwarf planets, they had to identify what was left. In the early 1800s, a name was given to the rocky planetesimals between Mars and Jupiter—the asteroid belt. Objects beyond the orbit of Neptune have been called trans-Neptunian objects (TNOs), Kuiper belt objects (KBOs), comets, and members of the Oort cloud. But what would the collective name for these objects be? The IAU calls them small solar system bodies.

Asteroids There are thousands of asteroids orbiting the Sun between Mars and Jupiter. They are rocky bodies that vary in diameter and have pitted, irregular surfaces. Some asteroids have satellites of their own, such as the asteroid Ida, shown in **Figure 28.28.** Astronomers estimate that the total mass of all the known asteroids in the solar system is equivalent to only about 0.08 percent of Earth's mass.

Reading Check **Describe** the asteroid belt.

As asteroids orbit, they occasionally collide and break into fragments. When an asteroid fragment, or any other interplanetary material, enters Earth's atmosphere it is called a **meteoroid.** As a meteoroid passes through the atmosphere, it is heated by friction and burns, producing a streak of light called a **meteor.** If the meteoroid does not burn up completely and part of it strikes the ground, the part that hits the ground is called a **meteorite.** When large meteorites strike Earth, they produce impact craters. Any craters visible on Earth must be young, otherwise they would have been erased by erosion.

Kuiper belt Like the rocky asteroid belt, another group of small solar system bodies that are mostly made of rock and ice lies outside the orbit of Neptune in the **Kuiper** (KI pur) **belt.** Most of these bodies probably formed in this region—30 to 50 AU from the Sun—from the material left over from the formation of the Sun and planets. Some, however, might have formed closer to the Sun and were knocked into this area by Jupiter and the other gas giant planets. Eris, Pluto, Pluto's moon Charon, and an ever-growing list of objects are being detected within this band; however, none of them has been identified as a comet. Comets come from the farthest limits of the solar system, the Oort cloud, shown in **Figure 28.29.**