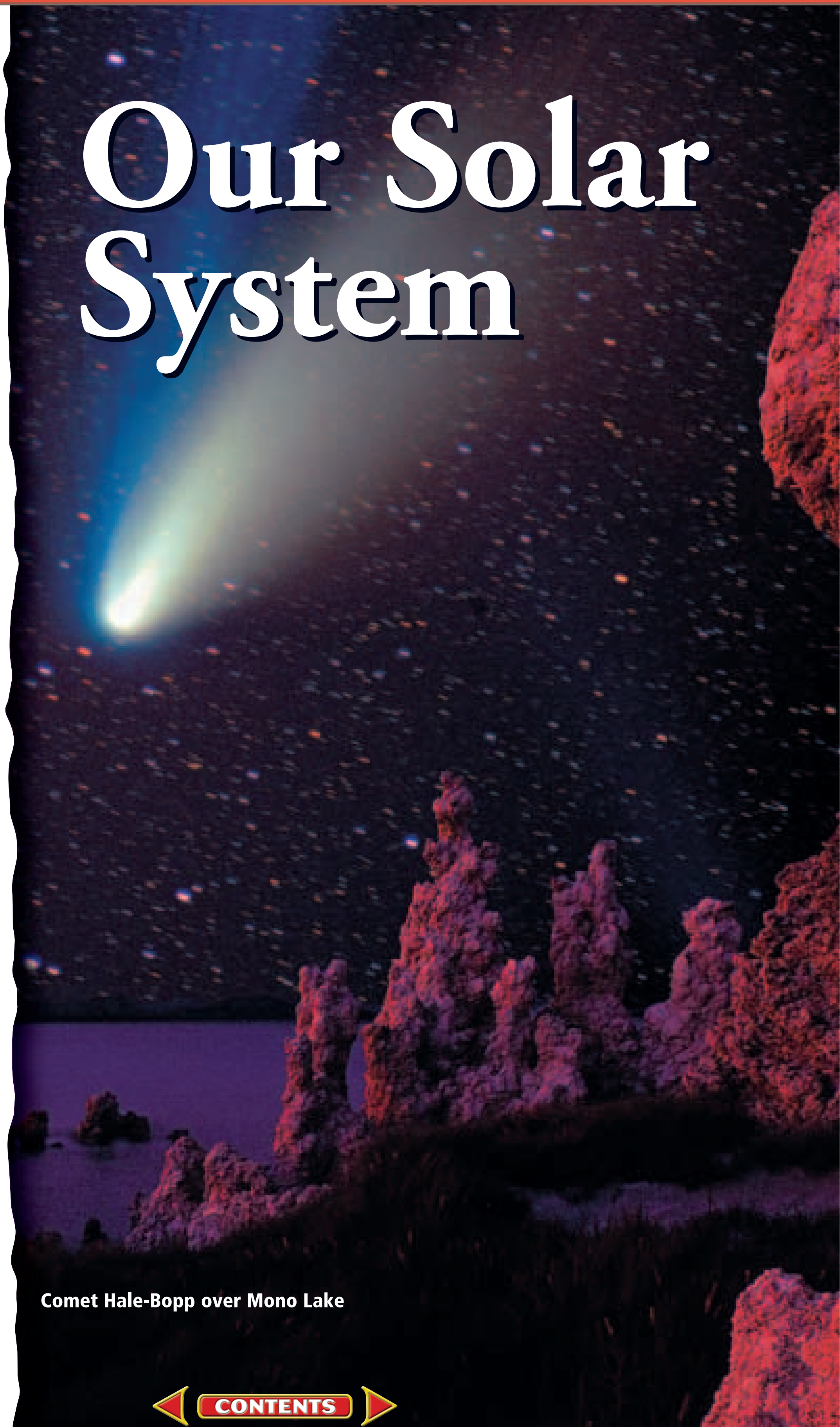
Chapter 29

Our Solar System



Comet Hale-Bopp over Mono Lake

What You'll Learn

- How gravity and orbits are related.
- The characteristics of planets and interplanetary bodies.
- What theory is used to describe the formation of the solar system.

Why It's Important

The laws of motion and universal gravitation explain how gravity governs the motions of the planets and other planetary bodies. Scientists base the model of our solar system on observations of the organization and nature of the planets and interplanetary bodies.

Earth Science Online

To find out more about our solar system, visit the Earth Science Web Site at earthgeu.com

Discovery Lab

Exploring Our Solar System

All nine planets in our solar system have been explored by uncrewed space probes, or soon will be. You can learn about these missions and their discoveries by finding information on the Web. The agency that sponsors a mission, the scientists involved, or both, usually create extensive Web sites full of information about the design, operation, and scientific goals of the mission.

1. Find at least one Web site for missions to four different planets. Or go to science.glencoe.com and follow the links.
2. Make a list of some of the key aspects of each mission.

Summarize Make an outline for each mission. Include the type of mission (flyby, lander, or orbiter), the scientific goals, the launch date and the date of arrival at the planet, and a summary of what was learned, or what scientists hope will be learned.

SECTION 29.1 *Overview of Our Solar System*

OBJECTIVES

- **Describe** *early models of our solar system.*
- **Examine** *the modern heliocentric model of our solar system.*
- **Relate** *gravity to the motions of celestial bodies.*

VOCABULARY

retrograde motion
astronomical unit
perihelion
aphelion
eccentricity

Earth is one of nine planets revolving around, or orbiting, the Sun. All the planets, as well as most of their moons, also called satellites, orbit the Sun in the same direction, and all their orbits, except Pluto's, lie near the same plane. The planets of our solar system have various sizes, surface conditions, and internal structures. Scientists have gathered much information about our solar system through the use of technologies developed in the twentieth century, but human beings have been watching the sky for thousands of years, and early ideas about the solar system were developed solely on the basis of Earth-based observations of the sky.

EARLY IDEAS

When viewed from Earth, the planets slowly change position each night relative to the position of the stars. Therefore, ancient astronomers could recognize the difference between stars and planets. These astronomers assumed that the Sun, planets, and stars orbited a stationary Earth in what is now known as a geocentric model, meaning "Earth centered."

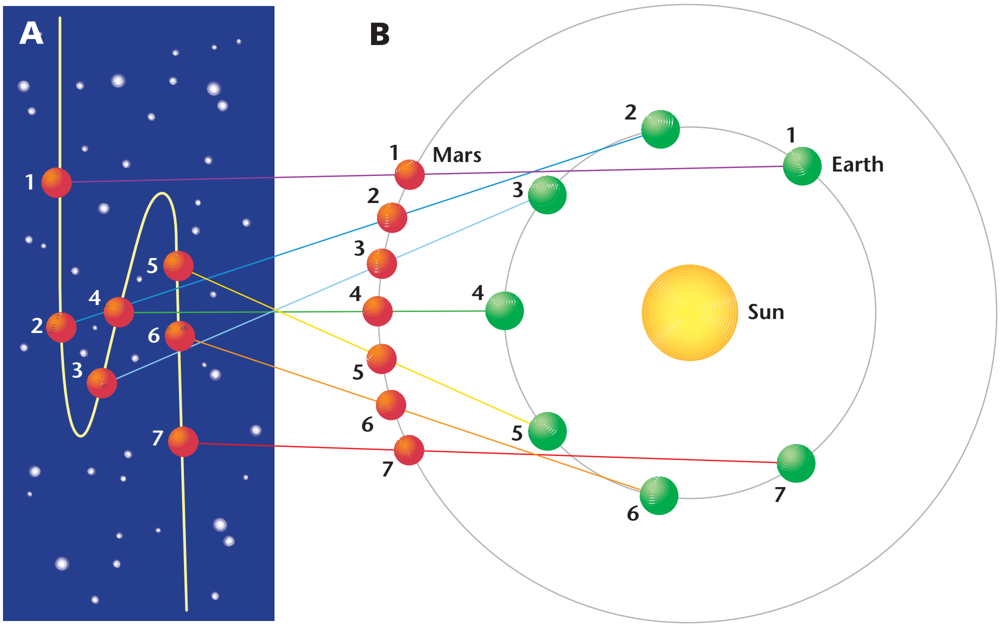
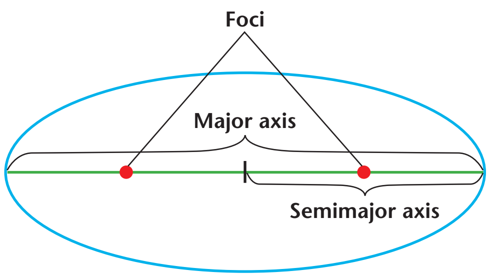


Figure 29-1 Mars appears to move from east to west (positions 3 and 4) for a short time **(A)** during its retrograde motion. The heliocentric model **(B)** explains retrograde motion. Follow the lines from Earth's orbital positions to Mars's orbital positions, and then to Mars's position in the sky. Retrograde motion is similar to passing a slower car on the freeway. It appears that the slower car is moving backwards relative to the background. (not to scale)

However, some aspects of planetary motion were difficult to explain with a geocentric model. For example, the normal direction of motion for all planets, as observed from Earth, is toward the east. Occasionally, however, a planet will move in the opposite direction across the sky in what is called **retrograde motion.** The retrograde motion of Mars is shown in ***Figure 29-1A.*** The search for a simple scientific explanation for retrograde motion motivated early astronomers to keep searching for a better model of our solar system.

In 1543, Polish scientist Nicolaus Copernicus suggested that the Sun was the center of the solar system. In this sun-centered, or heliocentric, model, Earth and the other planets orbit the Sun. This model provided a simple explanation of retrograde motion. In a Sun-centered model, the inner planets move faster in their orbits than the outer planets do. As Earth bypasses a slower-moving outer planet, as illustrated in ***Figure 29-1B,*** it appears that the outer planet temporarily moves backward in the sky.

Figure 29-2 The major axis passes through the foci of an ellipse, while the semimajor axis is half of the major axis.



Kepler's First Law The ideas of Copernicus were not initially accepted by the scientific community, but within a century, other astronomers were finding evidence that supported the heliocentric model. For example, from 1576–1601, a Danish astronomer, Tycho Brahe, made many accurate observations of planetary positions. Using Brahe's data, Johannes Kepler demonstrated that each planet orbits the Sun in a shape called an ellipse, rather than in a circle. This is known as Kepler's first law.

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An ellipse is an oval shape that is centered on two points instead of a single point, as in a circle. The two points are called the foci (*sing.* focus). The major axis is the line that runs through both foci; it is the maximum diameter of the ellipse, as illustrated in ***Figure 29-2.*** You will experiment with the foci and shapes of ellipses in the *MiniLab* on this page.

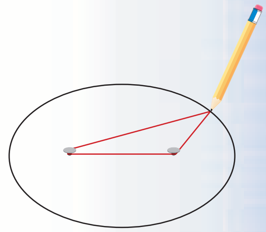
Each planet's elliptical orbit is a different shape and size, and the Sun is always at one focus. For each Sun-planet pair, half of the length of the major axis is called the semimajor axis. It is the average distance between the Sun and the planet. For the Sun and Earth, it is 1.496×10^8 km, or 1 **astronomical unit** (AU). The average distances between the Sun and each planet are measured in astronomical units, and therefore these distances are relative to Earth's average distance from the Sun.

Eccentricity A planet in an elliptical orbit is not at a constant distance from the Sun. When a planet is closest to the Sun in its orbit, it is at **perihelion,** and when it is farthest away, it is at **aphelion,** as shown in ***Figure 29-3.*** The shape of a planet's elliptical orbit is defined by **eccentricity,** which is the ratio of the distance between the foci to the length of the major axis. Eccentricity values range from 0 to 1. An eccentricity of 0 is a perfect circle, and an eccentricity of nearly 1 is a very elongated oval. An eccentricity equal to 1 is a parabola. Most of the planets have orbits that are not very eccentric, as shown in *Appendix J,* and are thus close to being circles. The length of time it takes for a planet or other body to travel a complete elliptical orbit around the Sun is called the orbital period.

MiniLab

Eccentricity

Measure the eccentricity of different ellipses. Eccentricity is the ratio of the distance between the foci to the length of the major axis.



Procedure

1. Tie a piece of string into a loop that fits on a piece of cardboard when it is laid out in a circle.
2. Place a sheet of paper on the cardboard.
3. Stick two pins through the paper close to the center but separated from each other by a few centimeters. Use caution when using sharp objects.
4. Loop the string over the pins and use the pencil to trace around them. Keep the string taut.
5. Measure the major axis and the distance between the pins. Calculate the eccentricity.
6. Repeat steps 3–5 for different separations of the pins.

Analyze and Conclude

1. What do the two pins represent?
2. How does the eccentricity change as the distance between the pins changes?
3. What kind of figure would you form if the two pins were at the same location? What would its eccentricity be?

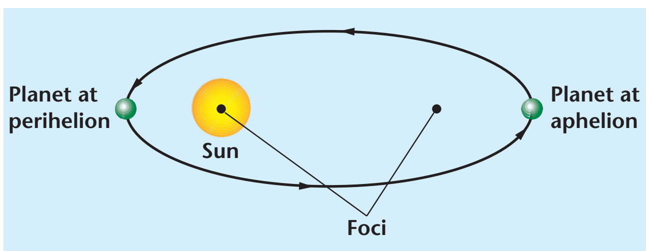


Figure 29-3 A planet is at perihelion when it is closest to the Sun in its orbit and at aphelion when it is farthest. (not to scale)

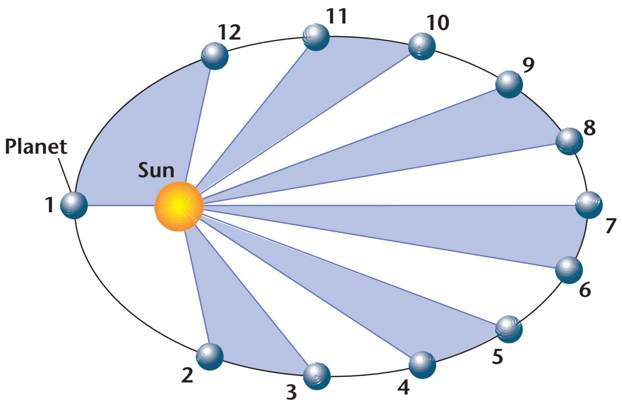


Figure 29-4 Because a planet moves fastest when close to the Sun and slowest when far from the Sun, equal areas are swept out in equal amounts of time, which is Kepler's second law. (not to scale)

Kepler's Second and Third Laws In addition to discovering the true shapes of planetary orbits, Kepler found that an imaginary line between the Sun and a planet sweeps out equal amounts of area in equal amounts of time, as illustrated in ***Figure 29-4.*** This is known as Kepler's second law. Kepler also derived a mathematical relationship between the size of a planet's ellipse and its orbital period. He found that the square of the orbital period (P) equals the cube of the semimajor axis of the orbital ellipse (a). This relationship, called Kepler's third law, is $P^2 = a^3$, where P is a unit of time measured in Earth years, and a is a unit of length measured in astronomical units. You will apply Kepler's third law to each planet in our solar system in the *Problem-Solving Lab* later in this chapter.

While Kepler was developing his ideas, Italian scientist Galileo Galilei became the first person to use a telescope to observe the sky. Galileo made many important discoveries that supported Copernicus's idea that the planets, including Earth, orbit the Sun. The most famous of Galileo's discoveries was that four moons orbit the planet Jupiter. This observation proved that not all celestial bodies orbit Earth, and therefore, Earth is not necessarily the center of the solar system. The underlying explanation for the heliocentric model still remained unknown, however, until 1684, when English scientist Isaac Newton published a mathematical and physical explanation of the motions of celestial bodies. Newton's concepts included the law of universal gravitation, which provided an explanation of how the Sun governs the motions of the planets.

Using Math

Using Numbers
Newton's law of universal gravitation, found on the next page, can be applied to any two objects that have mass. If one student has a mass of 50.0 kg and is 12.0 m away from another student that has a mass of 65.0 kg, what is the force of gravity between them?

Gravity and Orbits

Newton developed an understanding of gravity by observing the Moon's motion, the orbits of the planets, and the acceleration of falling objects on Earth. He realized that any two bodies attract each other with a force that depends on their masses and the distance between the two bodies. The force grows stronger in proportion to the product of the two masses, but diminishes as the square of the distance between them. For example, if the distance between Earth and the Moon were twice as great, the gravitational force between them would be only one-fourth as strong. At their normal distance apart, if the mass of the Moon were doubled and the mass of Earth were tripled, the force would be greater by a factor of 6.

Gravity Newton's statement of the relationship among the masses of two bodies and the force and distance between them is known as the law of universal gravitation. This law can be stated as follows: Every pair of bodies in the universe attract each other with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between them, or

$$F = G\frac{m_1 m_2}{r^2}.$$

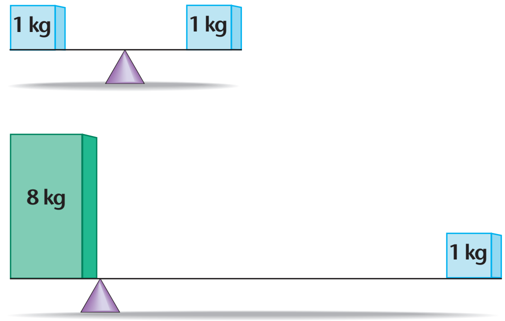


Figure 29-5 The center of mass is halfway between two equal mass objects, but closer to the heavier object when the objects are of unequal mass, similar to the pivot of a see-saw.

F is the force measured in newtons, and G is the universal gravitation constant, or 6.6726×10^{-11} meters cubed per kilogram per second squared. m_1 and m_2 are the masses of the bodies measured in kilograms, and r is the distance between the two bodies measured in meters.

Center of Mass Newton also determined that each planet orbits a point between it and the Sun called the center of mass. The center of mass is the balance point between two orbiting bodies, similar to the pivot point on a see-saw. If one person on a see-saw is much heavier than the other, the balance point is closer to the heavier person, as shown in ***Figure 29-5.*** In space, the same is true. If one of two bodies orbiting each other is more massive than the other, the center of mass is closer to the more massive body. If the two bodies have similar masses, the center of mass is near the middle position between them. For any planet and the Sun, the center of mass is just above the surface of the Sun, or within the Sun, because the Sun is much more massive than any planet, as you will learn in the following sections.

Section Assessment

1. Why is retrograde motion an apparent motion?
2. What were the contributions of Copernicus, Kepler, and Galileo in developing the Sun-centered model of the solar system?
3. Describe how the force between two bodies depends on their masses and the distance between them.
4. **Thinking Critically** Your weight is the gravitational force between you and Earth, and the separation between you and Earth is equal to Earth's radius. How would your weight be different if Earth's radius were larger or smaller than it is but Earth's mass remained the same?

Skill Review

5. **Comparing and Contrasting** Compare and contrast the geocentric and the heliocentric models of the solar system. For more help, refer to the *Skill Handbook.*

SECTION 29.2 The Terrestrial Planets

OBJECTIVES

- **Describe** *the properties of the terrestrial planets.*
- **Compare** *Earth with the other terrestrial planets.*

VOCABULARY

terrestrial planet
gas giant planet
precession

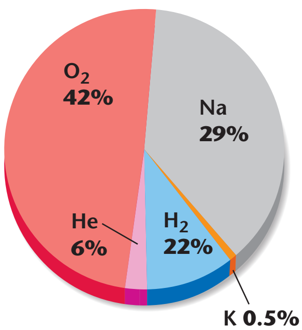
The nine planets of our solar system can be grouped into two main categories according to their basic properties. The inner four planets, called **terrestrial planets,** are close to the size of Earth and have solid, rocky surfaces. The terrestrial planets are Mercury, Venus, Earth, and Mars, in order from closest to farthest from the Sun. The next four planets from the Sun, called **gas giant planets,** are much larger, more gaseous, and lack solid surfaces. The gas giants include Jupiter, Saturn, Uranus, and Neptune. Pluto, the ninth planet from the Sun, has a solid surface, but it does not fit into either category. On the next several pages, we'll discuss each planet.

MERCURY

Mercury is the closest planet to the Sun and has no moons. Mercury is about one-third the size of Earth and has a smaller mass and radius, as shown in *Appendix J.* Radio observations in the 1960s revealed that Mercury has a slow spin of 1407.6 hours. After Mercury completes one orbit around the Sun, it has rotated one and a half times, and the opposite side of the planet faces the Sun. In two orbits, Mercury spins three times and the side originally facing the Sun faces the Sun again. Thus, in two of Mercury's years, three of Mercury's days have passed.

Atmosphere Unlike Earth, Mercury has essentially no atmosphere, and what little does exist is composed primarily of oxygen and sodium, as illustrated in ***Figure 29-6.*** 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 of all the planets in our solar system.

Figure 29-6 The major components in Mercury's atmosphere are oxygen, sodium, hydrogen, helium, and potassium.



Surface Most of what we know about Mercury is based on radio observations and images from a United States space probe mission, called *Mariner 10*, which passed close to Mercury three times in 1974 and 1975. Images from *Mariner 10* show that Mercury's surface, similar to the Moon's surface, is covered with craters and plains, as shown in ***Figure 29-7A.*** The plains of Mercury's surface are smooth and relatively crater free. It is thought that the plains were formed from lava flows that covered cratered terrain, much like the maria on the Moon. The surface gravity of Mercury is much greater than that of the Moon, and thus crater walls and peaks are lower and ejecta are shorter in length than those on the Moon. Mercury has a planetwide system of cliffs, called scarps, as shown in

Figure 29-7B. Scientists hypothesize that the scarps developed as Mercury's crust shrank and fractured early in the planet's geological history.

Interior Although scientists have no seismic data with which to analyze the interior of Mercury, the high density of the planet suggests that Mercury has an extensive nickel-iron core, filling about 42 percent of Mercury's volume. The detectable magnetic field, only 1 percent of Earth's magnetic field strength, suggests that Mercury has a molten zone in its interior. Mercury's small size, high density, and probable molten interior zone resemble what Earth might be like if its crust and mantle were removed. These observations suggest that Mercury was originally much larger, with a mantle and crust similar to Earth's, and that the outer layers may have been lost in a collision with another celestial body early in its history.

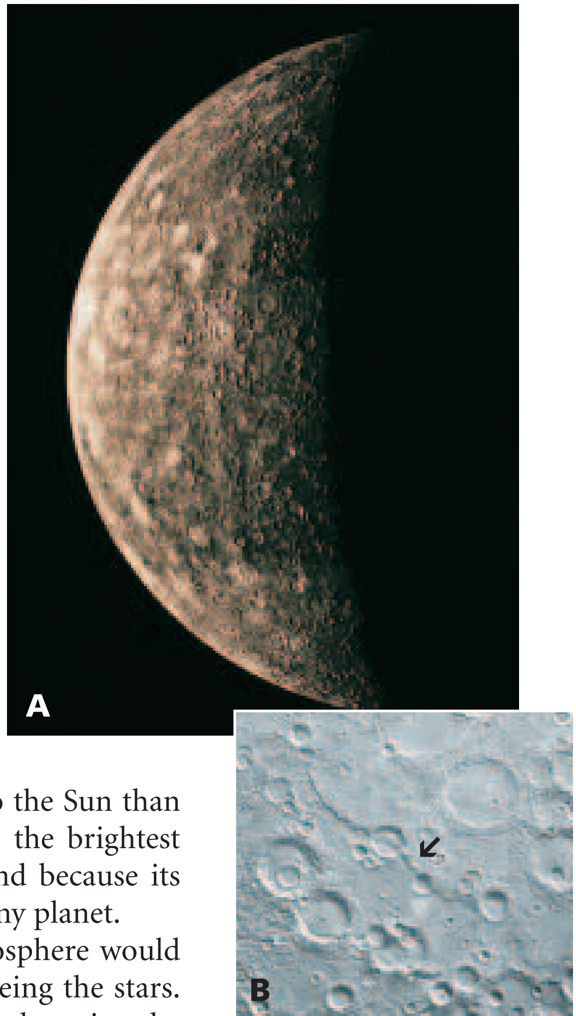


Figure 29-7 This composite image of Mercury **(A)** was photographed by *Mariner 10.* Discovery Scarp **(B)** is 500 km long and 2 km high.

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 Earth's nighttime sky because it is close and because its albedo is 0.75. The albedo of Venus is the highest of any planet.

The thick clouds that are present in Venus's atmosphere would prevent an observer on the surface of Venus from seeing the stars. These clouds also prevent astronomers from directly observing the surface, except at radio wavelengths. In the 1960s, radar measurements showed that the surface of Venus is very hot, and that Venus is rotating slowly. One day on Venus is 243 Earth days in length. Radar measurements also revealed Venus's clockwise spin, which is opposite the spin of most planets. The backward spin exhibited by Venus, called retrograde rotation, means that for an observer on Venus, the Sun would rise in the west and set in the east. Astronomers hypothesize that the retrograde rotation of Venus may have been caused by a collision between Venus and another body early in our solar system's history.

Today, astronomers know a lot about Venus as a result of close-up observations made by several United States and Soviet (later Russian) spacecraft. Some probes landed on the surface of the planet and made observations there, while others flew by. The 1978 *Pioneer-Venus* and the 1989 *Magellan* missions of the United States used radar to map up to 98 percent of the surface of Venus.

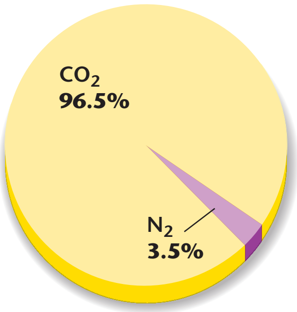


Figure 29-8 The major components of Venus's atmosphere are carbon dioxide and nitrogen.

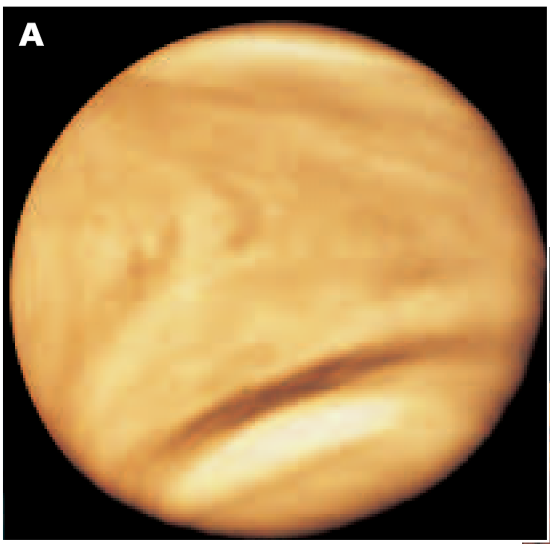
Atmosphere Venus is the planet most similar to Earth in physical properties, such as diameter, mass, and density, as shown in *Appendix J,* but its surface conditions are vastly different from those on Earth. The average surface temperature of Venus is extremely hot, about 737 K (464°C), as compared to Earth's average surface temperature of 288 K (15°C). On the surface of Venus, it is hot enough to melt lead! The atmospheric pressure on Venus is 92 atmospheres—much higher than the 1 atmosphere at sea level on Earth. The pressure from the atmosphere on Venus would make you feel like you were under 915 m of water.

The atmosphere of Venus is primarily carbon dioxide and nitrogen, as illustrated in ***Figure 29-8.*** How does this compare to Earth's atmospheric composition? Similar to Earth, Venus has clouds. But instead of being composed of water vapor and ice, clouds on Venus, shown in ***Figure 29-9A,*** are made of sulfuric acid and are 35 km thick. If it were to rain on Venus, the rain would be sulfuric acid.

Venus has a greenhouse effect, like Earth, but Venus's is more efficient. As you learned in Chapter 14, greenhouse gases in Earth's atmosphere trap infrared radiation and keep Earth at higher temperatures than those that would exist if there were no atmosphere. Carbon dioxide, one of Earth's greenhouse gases, has a high concentration in Venus's atmosphere, which prevents infrared radiation from escaping and keeps the surface extremely hot. In fact, it is so hot that liquid water can't exist. Venus is the hottest planet, even though it is not the closest to the Sun.

Surface The *Magellan* orbiter used radar reflection measurements to map the surface of Venus in fine detail. The surface has been smoothed by volcanic lava flows, as shown in ***Figure 29-9B,*** and it has only a few impact craters. The most recent global episode of volcanic activity took place about 500 million years ago, and therefore the surface of Venus is relatively young. Unlike Earth, there is little evidence of current tectonic activity on Venus, and there is no well-defined system of crustal plates.

Figure 29-9 The clouds in the atmosphere of Venus **(A)** obscure the surface. By using the radar of *Magellan,* astronomers have been able to map the surface and discover features like the volcano Maat Mons and the surrounding surface smoothed by volcanic lava flows **(B).**



Interior The size and density of Venus are similar to Earth, so the internal structure is most likely similar. However, astronomers have no seismic data with which to prove this. It is theorized that Venus has a liquid metal core that extends halfway to the surface. There is no measurable magnetic field despite this liquid core, which is probably due to Venus's slow rotation rate.

EARTH

Earth, shown in ***Figure 29-10,*** is the third planet from the Sun. Earth has many unique properties when compared with the other planets. Its distance from the Sun and its nearly circular orbit allow liquid water to exist on its surface in all three states: solid, liquid, and gas. Liquid water is required for life, and Earth's vast abundance of liquid water has been important for the development and existence of life on our planet. In addition, our planet's moderately dense atmosphere, which is composed primarily of 78 percent nitrogen and 21 percent oxygen, and a mild greenhouse effect also support conditions suitable for life.

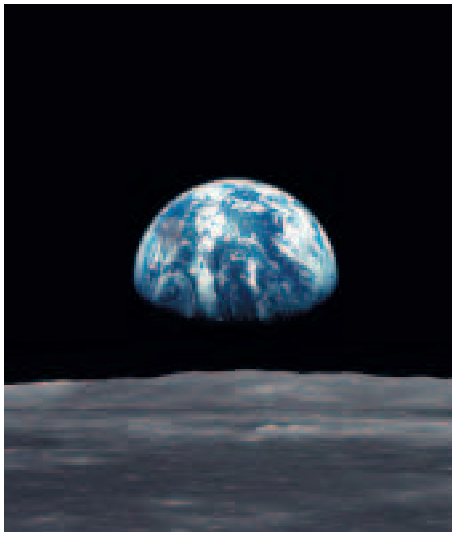
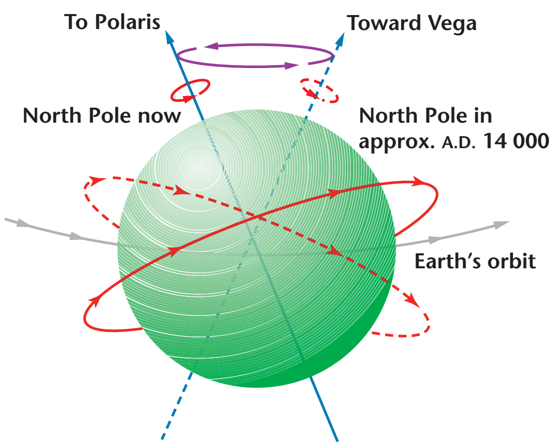


Figure 29-10 This shows Earth as seen by the Apollo astronauts orbiting the Moon.

Precession Earth's axis is tilted, as you have learned, and this tilt creates our seasons. As you learned in Chapter 14, Earth's axis is wobbling, like a toy top that wobbles if you give it a small sideways push while it is spinning. This wobble in Earth's rotational axis, shown in ***Figure 29-11,*** is called **precession.** It takes Earth's rotational axis about 26 000 years to go through one cycle of precession. The sideways pull that causes precession comes from the Moon's gravitational force on Earth, as well as the Sun's gravitational force. However, the Sun's gravitational force plays a lesser part in Earth's precession.



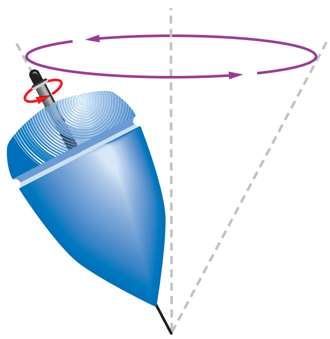


Figure 29-11 Earth precesses, or wobbles, on its axis, much like a toy top. In 12 000 years, our new north star will be Vega.

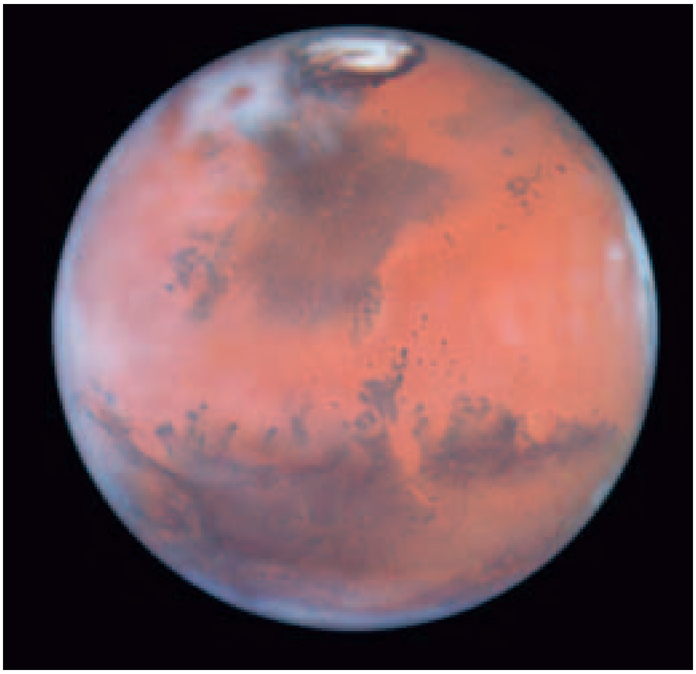


Figure 29-12 This view of Mars, taken by the *Hubble Space Telescope (HST),* shows its surface, its atmosphere, and one of its polar caps.

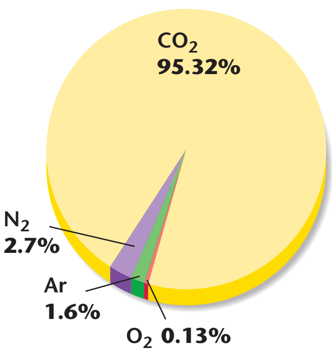
MARS

Mars is the fourth planet from the Sun and the outermost of the terrestrial planets. It is often referred to as the red planet because of its reddish surface color, shown in ***Figure 29-12,*** which is caused by a high iron content in the soil. Mars is smaller and less dense than Earth, as shown in *Appendix J,* and has two irregularly-shaped moons, Phobos and Deimos, which are most likely captured asteroids.

Mars has been explored by telescopes on Earth and with probes that have flown by, orbited, or landed. In the 1960s, the United States sent a spacecraft, *Mariner 4,* to explore Mars. Later missions included *Mariner 9,* in 1971, and two *Viking* landers in 1976. More recent missions have been the *Mars Climate Orbiter* in 1998 and the *Mars Exploration Rover Mission* in 2003, which are all part of a long-term NASA plan to explore Mars for evidence of preexisting life.

Atmosphere The composition of Mars's atmosphere, shown in ***Figure 29-13,*** is similar to Venus's atmosphere, but the density and pressure in Mars's atmosphere are much lower, and therefore Mars does not have a strong greenhouse effect, as Venus does. Although the atmosphere is thin, it is turbulent, so there is a constant wind on Mars. Dust storms in the atmosphere may last for weeks at a time.

Figure 29-13 The major components of Mars's atmosphere are carbon dioxide, nitrogen, argon, and oxygen.



Surface The southern and northern hemispheres of Mars have different types of surfaces. The southern hemisphere is a heavily cratered, highland region, resembling the highlands of the Moon. The northern hemisphere is dominated by plains that are sparsely cratered. Scientists theorize that great lava flows covered the once-cratered terrain of the northern hemisphere. Four gigantic shield volcanoes are located in the northern hemisphere, near a region called the Tharsis Plateau. The largest volcano is Olympus Mons, which is also the largest mountain in the solar system. The base of Olympus Mons would cover the state of Colorado; it is three times higher than Mt. Everest. An enormous canyon, Valles Marineris, shown in ***Figure 29-14,*** lies on the Martian equator and splits the Tharsis Plateau. This canyon seems to have formed as a fracture when the Tharsis Plateau was uplifted more than 3 billion years ago.

Other Martian surface features include dried river and lake beds, outflow channels, and runoff channels. These are all erosional features that suggest that liquid water once existed on the surface of Mars. Astronomers hypothesize that the atmosphere must have once been much warmer, thicker, and richer in carbon dioxide, which would have allowed water to exist on Mars. Although there is a relatively small amount of ice at the poles, astronomers are still searching for water at other locations on the Martian surface today.

Mars has polar ice caps covering both poles. The caps grow and shrink with the seasons on Mars. Martian seasons are caused by a combination of a tilted axis and a highly elongated orbit. Both caps are made of carbon dioxide ice, which you may know as "dry ice." Water ice lies beneath the carbon dioxide ice in the northern cap, shown in ***Figure 29-12,*** and is exposed during the northern hemisphere's summer when the carbon dioxide ice evaporates. There may also be water ice beneath the southern cap, but the carbon dioxide ice never completely evaporates to expose the water ice.

Figure 29-14 Valles Marineris stretches for more than 4000 km. A few large volcanoes can be seen in the upper left.

Interior Astronomers are unsure about the internal structure of Mars. They hypothesize that there is a core of iron and 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 hypothesize 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 ASSESSMENT

1. List the similarities and differences between Mercury and the Moon, and between Mercury and Earth.
2. Explain why surface conditions on Venus and Earth are so different.
3. Why do astronomers hypothesize that the southern polar cap of Mars has water ice under the carbon dioxide ice?
4. What evidence do astronomers use to support the hypothesis that there was once tectonic activity on Mercury, Venus, and Mars?
5. **Thinking Critically** What do you think the terrestrial planets would be like today if major impacts had not played a role in their formation and evolution?

SKILL REVIEW

6. **Making Graphs** Using *Appendix J,* create a graph showing the distance from the Sun for each terrestrial planet on the *x*-axis and the orbital period in Earth days on the *y*-axis. For more help, refer to the *Skill Handbook.*

earthgeu.com/self_check_quiz

CONTENTS

SECTION 29.3 The Gas Giant Planets

OBJECTIVES

- **Describe** *the properties of the gas giant planets.*
- **Identify** *the unique nature of the planet Pluto.*

VOCABULARY

liquid metallic hydrogen
belt
zone

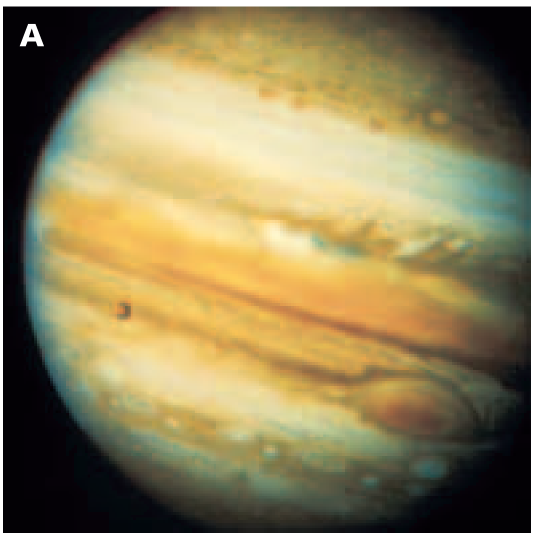
The interiors of the gas giant planets are composed of fluids, either gaseous or liquid, and possibly small, solid cores. They are composed primarily of lightweight elements such as hydrogen, helium, carbon, nitrogen, and oxygen, and they are very cold at their surfaces. The gas giants have many satellites as well as ring systems, and, as their name implies, they 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. You will compare the relative sizes and distances from the Sun of the nine planets in the *Design Your Own GeoLab* at the end of the chapter.

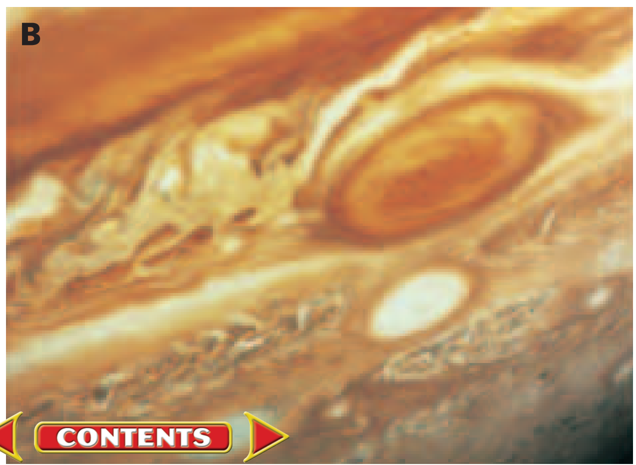
JUPITER

Jupiter is the largest planet and the fifth planet from the Sun. The diameter of Jupiter is 11 times larger than Earth's, and only 10 times smaller than the Sun's. Jupiter's mass, shown in *Appendix J,* makes up 70 percent of all planetary matter in our solar system. From Earth, Jupiter appears quite bright because of its albedo of 0.343. Telescopic observations reveal that Jupiter has a banded appearance, as shown in ***Figure 29-15A,*** as a result of flow patterns in its atmosphere. Jupiter has four major satellites, which were discovered by Galileo, in addition to many smaller ones, which were discovered by flyby space probes and recent observations.

Jupiter has been explored by several United States space probes. The first were the *Pioneer 10* and *Pioneer 11* missions, which arrived at Jupiter in 1973 and 1974, respectively. In 1979, the *Voyager 1* and *Voyager 2* missions discovered several new satellites and a thin, dim ring around Jupiter. They also detected volcanic activity on Jupiter's closest major moon, Io. In 1995, the United States spacecraft *Galileo* arrived at Jupiter and dropped a probe into the clouds while the main spacecraft orbited the planet for five years and made observations.

Figure 29-15 Jupiter **(A),** as photographed by *Voyager 1,* has a banded appearance. *Voyager 1* also photographed Jupiter's Great Red Spot **(B).**





Atmosphere Jupiter has a low density, 1326 kg/m^3, for its huge size because it is composed of lightweight elements. Hydrogen and helium make up the majority of Jupiter's atmospheric gas, as illustrated in ***Figure 29-16.*** In Jupiter's atmosphere, these elements remain in a gas or liquid form. Below the liquid hydrogen, there 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. Theoretical models of Jupiter suggest that Jupiter might have an Earth-sized solid core made of heavier elements that have sunk to the center of the planet.

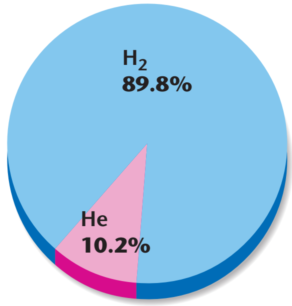


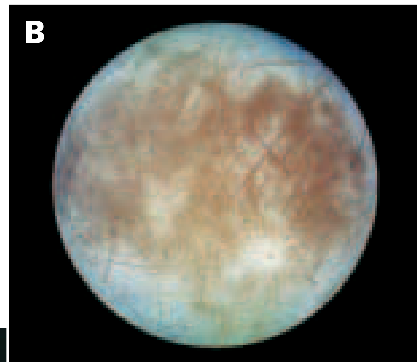
Figure 29-16 The major components of Jupiter's atmosphere are hydrogen and helium.

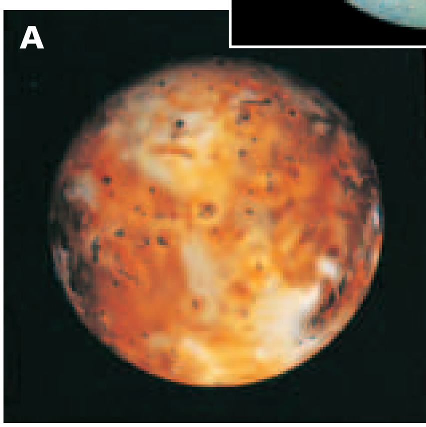
The rotation of Jupiter is extremely rapid for its huge size. Jupiter spins on its axis in a little less than 10 hours, making it the shortest day in the solar system. This rapid rotation distorts the shape of the planet so that the diameter through its equatorial plane is 7 percent larger than the diameter through its poles. Jupiter's rapid rotation causes its clouds to flow rapidly as well, in alternating cloud types 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 the rotation-driven flows in Earth's atmosphere. ***Figure 29-15B*** shows Jupiter's Great Red Spot, which is an atmospheric storm that has been rotating around Jupiter for more than 300 years.

Moons and Rings Jupiter's four largest moons, Io, Europa, Ganymede, and Callisto, are called Galilean satellites, after their discoverer. All but one of them are bigger than Earth's moon, and all are larger than Pluto. These four moons are composed of ice and rock mixtures. The ice content is lower in Io and Europa, shown in ***Figure 29-17,*** because they have been squeezed and heated to a greater extent by Jupiter's gravitational force than the outer moons. In fact, Io has been heated to the point of becoming almost completely molten inside and undergoes constant volcanic eruptions. Gravitational heating has melted the ice in Europa, at least in the past, and astronomers hypothesize that this moon still has a subsurface ocean of liquid water.

The ring of Jupiter was discovered in images from the *Voyager 1* mission. Jupiter's ring is 6400 km wide. Its discovery proved that Saturn is not the only gas giant that has rings. In fact, it is now known that all four of the gas giant planets have rings.

Figure 29-17 Io is the closest major moon to Jupiter **(A).** The next closest is Europa **(B).**





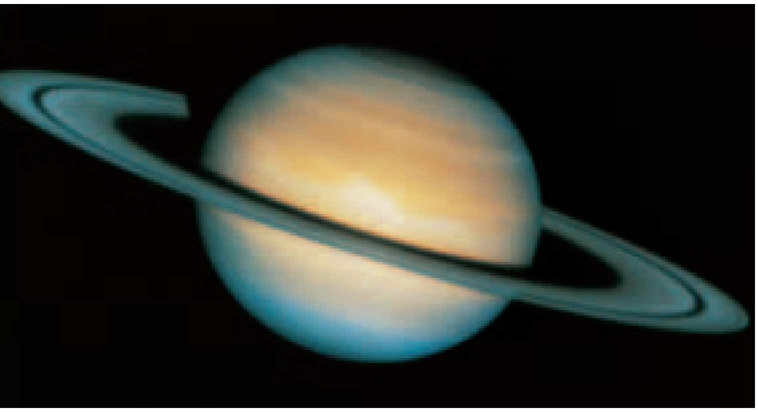


Figure 29-18 This image of Saturn was captured by *HST,* on December 1, 1994.

Saturn

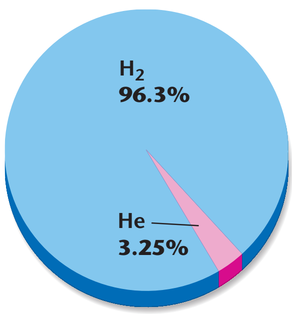
Saturn is the sixth planet from the Sun and the second-largest planet in the solar system. Saturn is shown in ***Figure 29-18.*** Four space probes have visited Saturn, including *Pioneer 10, Pioneer 11,* and *Voyager 1* and *2*. In 2004, the United States *Cassini* mission, launched in 1997, will arrive at Saturn and go into orbit around the planet. It will also release a probe into the atmosphere of Titan, Saturn's largest moon, to explore surface conditions there.

Atmosphere Saturn is not quite as large as Jupiter and has an average density, shown in *Appendix J,* that is actually lower than that of water. Similar to Jupiter, Saturn rotates rapidly for its size and has flowing belts and zones. Saturn's atmosphere is dominated by hydrogen and helium, as illustrated in ***Figure 29-19,*** but it also includes ammonia ice near the top of the clouds. The internal structure of Saturn is also probably similar to Jupiter. It is most likely fluid throughout with a small, solid core and a magnetic field that is 1000 times stronger than Earth's. Saturn's magnetic field is aligned with its rotational axis, which is unusual among the planets.

Moons and Rings The most striking feature of Saturn is its ring system, shown in ***Figure 29-20,*** which has much broader and brighter rings than those of the other gas giant planets. Saturn's rings are composed of pieces of rock and ice that range from microscopic to the size of houses. There are seven major rings, but each ring is actually made up of narrower rings, called ringlets, and many open gaps. These ringlets and gaps are caused by the gravitational effects of the many moons of Saturn. The rings are very thin, less than 200 m thick, because rotational forces keep all the particle orbits confined to Saturn's equatorial plane. The ring particles have not combined to form a large satellite because Saturn's gravity prevents particles very close to the planet from sticking together. This is why the major moons of the gas giant planets are always found farther out than the rings.

Until recently, astronomers hypothesized that the ring particles were simply left over from the time when Saturn and its moons formed. Now, however, many astronomers hypothesize it more likely that the ring particles are debris left over when a moon was destroyed by a collision with an asteroid or other object, or was ripped apart by Saturn's gravity. Some astronomers hypothesize that Saturn and the other gas giant planets may form new ring systems from time to time as collisions or gravitational effects occasionally destroy their moons.

Figure 29-19 The major components of Saturn's atmosphere are hydrogen and helium.



Saturn's many satellites include the giant Titan, seven intermediate-sized moons, and a number of small moons. Titan is larger than Earth's moon, and its atmosphere is made of nitrogen and methane. Methane may exist as a gas, a liquid, and ice on Titan's surface, similar to the three phases of water on Earth's surface.

Figure 29-20 This image taken by *Voyager 1* shows the many ringlets that comprise the rings of Saturn.

URANUS

The seventh planet from the Sun, Uranus, was discovered accidentally in 1781. A bluish object was spotted through a telescope, and after tracking it for a couple of days, it was found that the object moved relative to the stars. It was a planet. In 1787, two of Uranus's larger moons, Titania and Oberon, were discovered. Today, we know that Uranus has many moons and 10 rings. In 1986, the United States *Voyager 2* mission visited Uranus and provided detailed information about the planet, including the existence of new moons and rings.

Atmosphere Uranus is 4 times as large and 15 times as massive as Earth, as shown in *Appendix J.* It has a blue, velvety appearance, as shown in ***Figure 29-21A,*** which is caused by its atmospheric composition. The methane gas in Uranus's atmosphere reflects blue light back into space, although most of the atmosphere is composed of helium and hydrogen, as illustrated in ***Figure 29-21B.*** There are very few clouds present, and they differ little in brightness and color from the surrounding atmosphere, making them difficult to detect. In addition, there are no distinct belts or zones like those observed on Jupiter and Saturn, which contributes to Uranus's featureless appearance. The internal structure of Uranus is similar to Jupiter and Saturn; it is completely fluid except for a small, solid core. Uranus also has a strong magnetic field.

The rotational axis of Uranus is tipped over so far that the north pole almost lies in its orbital plane. Astronomers hypothesize that Uranus was knocked sideways by a massive collision with a passing object, such as a very 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 and Uranus's long trip around the Sun. Uranus's atmosphere keeps the planet at a temperature of 58 K (–215°C).

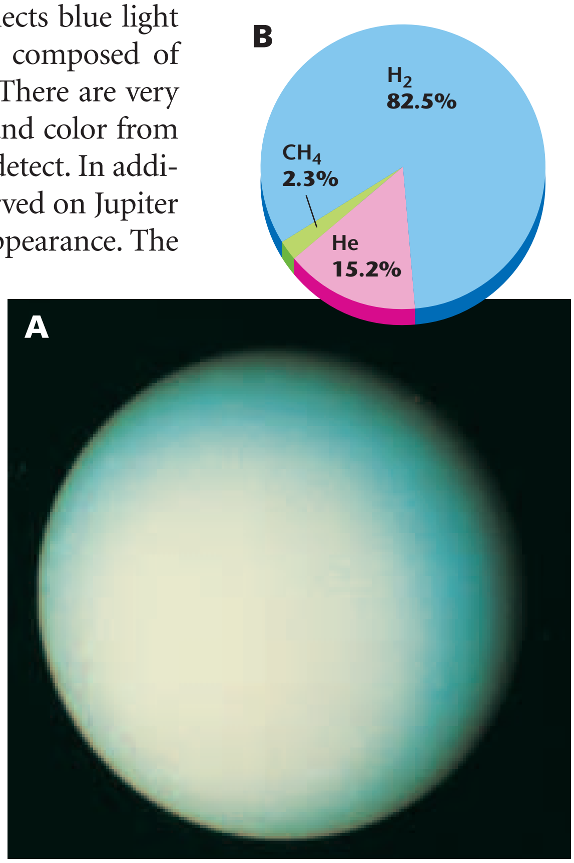


Figure 29-21 Uranus **(A),** photographed by *Voyager 2,* appears to be blue and featureless because of the methane (CH_4) in its atmosphere **(B).**

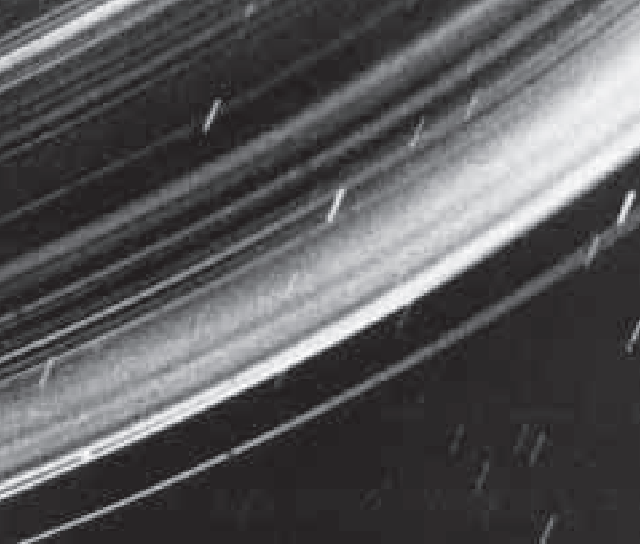


Figure 29-22 The rings of Uranus, photographed by *Voyager 2,* are very dark. Astronomers hypothesize that they are made of carbon compounds.

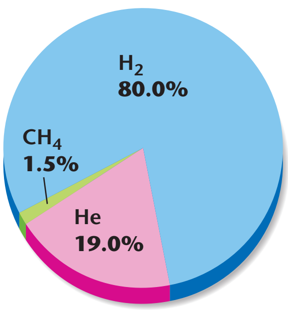
Moons and Rings The known moons and rings of Uranus orbit in the planet's equatorial plane. New moons are frequently being discovered, so Uranus's moon counts, like Jupiter's and Saturn's, are always changing. Uranus's rings, shown in ***Figure 29-22,*** are very dark—almost black. This is why they weren't discovered until the brightness of a star behind the rings dipped as Uranus moved in its orbit and the rings blocked the light.

Neptune

The existence of Neptune was predicted before it was discovered. The prediction was 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. Few details can be observed on Neptune with an Earth-based telescope, but the *Voyager 2* probe flew past this planet in 1989 and sent back new data and images of the planet.

Atmosphere Neptune is slightly smaller and denser than Uranus, but it is still about four times as large as Earth, as shown in *Appendix J.* Other similarities between Neptune and Uranus include their bluish color caused by methane in the atmosphere, atmospheric compositions, as illustrated in ***Figure 29-23,*** temperatures, magnetic fields, interiors, and particle belts. Unlike Uranus, however, Neptune, shown in ***Figure 29-24A,*** has distinctive clouds and atmospheric belts and zones similar to those of Jupiter and Saturn. In fact, Neptune had a persistent storm, the Great Dark Spot, with characteristics similar to Jupiter's Great Red Spot. The storm disappeared from Neptune in 1994.

Figure 29-23 Like Uranus, the major components of Neptune's atmosphere are hydrogen, helium, and methane.



Moons and Rings Neptune has many moons, the largest being Triton. Triton, shown in ***Figure 29-24B*** has a retrograde orbit, which means that it orbits backward, unlike virtually every other large satellite in the solar system. Triton also has a thin atmosphere and nitrogen geysers. The geysers are caused by nitrogen gas below the surface in Triton's south polar ice cap expanding and erupting when heated by the Sun.

The *Voyager 2* flyby increased our knowledge of Neptune's rings, which previously had been only indirectly observed. The six rings are composed of microscopic-sized dust particles. Some parts of the outermost ring appear much brighter than other parts because of the clumping of material. Scientists theorize that these clumps do not spread out evenly in the ring because of the gravitational effects of Neptune's moons.

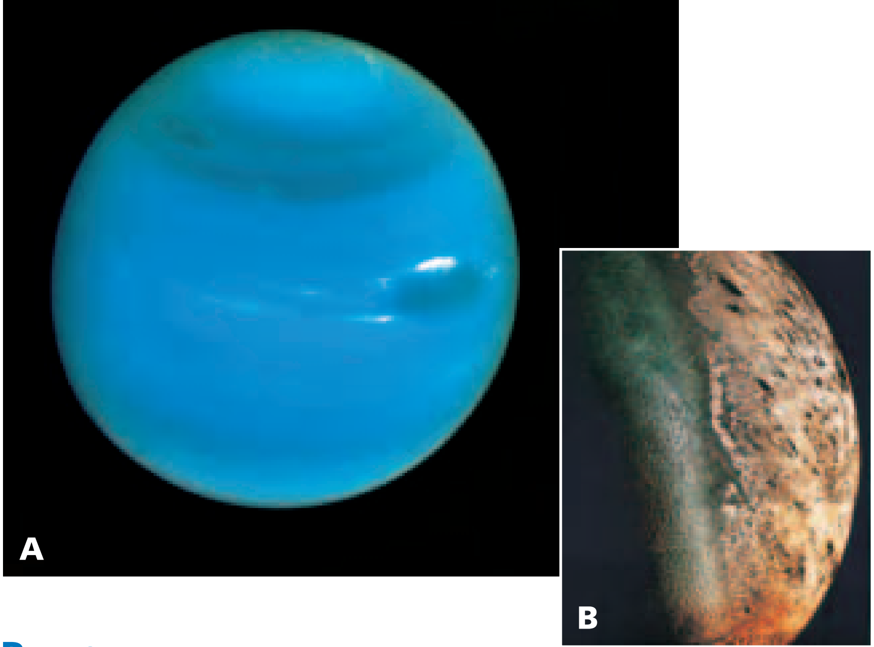


Figure 29-24 Neptune **(A)** has bands in its atmosphere. This image, taken before 1994, shows the Great Dark Spot right of center. This image of Triton **(B),** taken by *Voyager 2,* shows the sooty material of the nitrogen geysers that have been blown downwind by Triton's thin atmosphere.

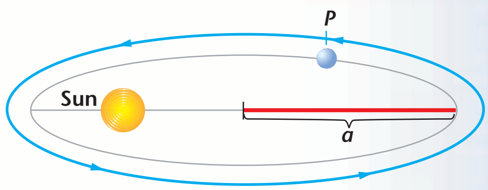
Pluto

The ninth planet in our solar system, Pluto, was discovered in 1930. Pluto is very different from the other eight planets of our solar system. Even though it has a solid surface, Pluto is not classified as a terrestrial planet because of its low density and small size. With its solid surface, Pluto does not have properties characteristic of the gas giant planets either. The density of Pluto indicates that it is made of half ice and half rock, and it is smaller than Earth's moon. The atmosphere is composed of methane and nitrogen, but in unknown quantities.

Problem-Solving Lab

Using Numbers

Test 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 data from *Appendix J* to calculate P^2 and a^3 for each of the nine planets.
2. Compare P^2 to a^3 for each planet.

Thinking Critically

3. Does Kepler's third law fit each of the planets?
4. If Uranus, Neptune, and Pluto had been discovered in Kepler's time, do you think he would have still believed in his law? Explain.
5. What would be the orbital period of an asteroid orbiting the Sun at 2.5 AU?
6. What is the semimajor axis for comet Halley, which has an orbital period of 76 years?

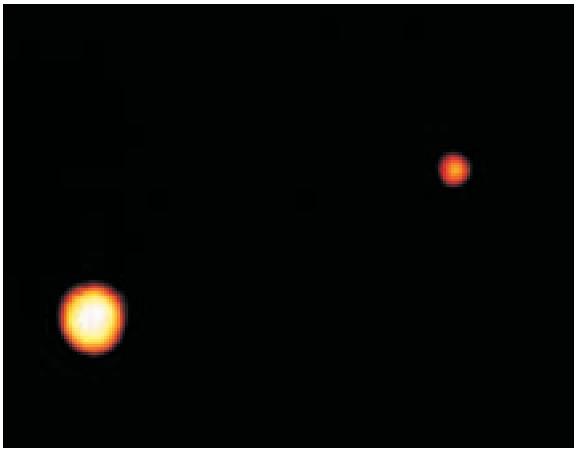


Figure 29-25 This image of Pluto and Charon, taken by *HST* on February 21, 1994, is the best image to date of the pair. Pluto and Charon are separated by a distance of 19 640 km.

The orbit of Pluto is so eccentric that at aphelion, it is 50 AU from the Sun, and at perihelion, it is almost 30 AU from the Sun. While at perihelion, Pluto is closer to the Sun than Neptune is. This happened last between 1978 and 1998. No space probes have traveled out to Pluto, although NASA is planning a flyby mission of Pluto.

Pluto's rotational axis is tipped so far over that its north pole actually points south of its orbital plane. Pluto has a satellite, called Charon, which orbits in Pluto's equatorial plane. Pluto and Charon, shown in ***Figure 29-25,*** have masses that are the most similar of any planet-satellite pair in the solar system. They are in synchronous rotation with each other, which means that each one keeps the same side facing the other. If you visited Pluto at a location on the side facing Charon, you would always see Charon in the sky overhead, throughout day and night.

Many of Pluto's properties, shown in *Appendix J,* are more similar to those of the gas giants' large moons than they are to those of any other planet. One theory suggests that Pluto was once a satellite of Neptune that escaped as a result of a near-collision with Triton. This would help explain Pluto's highly eccentric, tilted orbit and the unusual tilt of its rotational axis, as well as Triton's backward orbital motion. According to another theory, Pluto's composition and eccentric orbit suggest that it is related to a comet.

SECTION ASSESSMENT

1. In what two ways does Jupiter's rapid rotation affect the planet?
2. Describe the rings of Saturn and how they are thought to have formed.
3. What are the similarities between Uranus and Neptune?
4. Describe properties of Pluto that exclude it from being classified as either a terrestrial planet or a gas giant planet.
5. **Thinking Critically** Pluto and Neptune's orbits are arranged in such a way that Pluto is sometimes within Neptune's orbit. Despite this, collisions between the two are not possible. What are some possible reasons for this?

SKILL REVIEW

6. **Using Tables** Using values from *Appendix J,* compare the mass of Jupiter with the total mass of the other eight planets. Also, compare the total mass of all the planets, including Jupiter, with the mass of the Sun. For more help, refer to the *Skill Handbook.*

SECTION 29.4 Formation of Our Solar System

Now that you know some of the characteristics of the solar system and the nature of the celestial bodies that occupy the Sun's vicinity, you are prepared to think about how the solar system formed. Astronomers use Earth-based observations and data from probes to derive theories about how our solar system formed. The significant observations related to our solar system's formation include the shape of our solar system, the differences among the planets, and the oldest planetary surfaces, asteroids, meteorites, and comets.

OBJECTIVES

- **Summarize** *the properties of the solar system that support the theory of the solar system's formation.*
- **Describe** *how the planets formed from a disk surrounding the young Sun.*
- **Explore** *remnants of solar system formation.*

VOCABULARY

planetesimal
asteroid
meteoroid
meteor
meteorite
comet
coma
nucleus
meteor shower

A Collapsing Interstellar Cloud

Stars and planets form from clouds of gas and dust, called interstellar clouds, which exist in space between the stars. The interstellar clouds consist mostly of gas, especially hydrogen and helium. Dust makes interstellar clouds look dark because the dust blocks the light from stars within or behind the clouds. The dust can be thought of as a kind of interstellar smog. Conversely, light from stars reflects off the dust and partially illuminates the clouds. The clouds can also be heated by stars, which can cause them to glow on their own. This is why the interstellar clouds often appear as blotches of light and dark, as shown in ***Figure 29-26.***

Many interstellar clouds can be observed along the Milky Way in regions that have relatively high concentrations of interstellar gas and dust. The density of interstellar gas is very low, much lower than even the best laboratory vacuums created by scientists. However, an interstellar cloud can start to condense as a result of gravity and become concentrated enough to form a star and possibly planets. Astronomers hypothesize that our solar system began in this way.

Figure 29-26 This mosaic of images of the Orion Nebula was taken by *HST.* The Orion Nebula is home to newly forming stars.

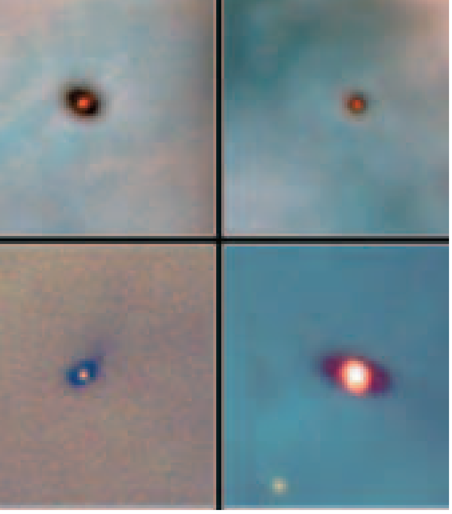


Figure 29-27 These images, taken by *HST* on November 20, 1995, show four young stars with disks of gas and dust around them. Astronomers often use radio and infrared telescopes which can penetrate the interstellar clouds to find these young stars.

At first, the collapse is slow, but it accelerates and the cloud soon becomes much denser at its center. If a cloud was rotating at all to begin with, it will spin faster and faster as it contracts, for the same reason that ice-skaters spin faster as they pull their arms close to their bodies. As the collapsing cloud spins, the rotation slows the collapse in the equatorial plane, and the cloud becomes flattened. The cloud eventually becomes a rotating disk with a dense concentration at the center, as shown in ***Figure 29-27.***

Sun and Planet Formation

The disk of dust and gas that formed the Sun and planets is known as the solar nebula. The dense concentration of gas at the center of this rotating disk eventually became the Sun. You will learn more about the Sun's formation as well as the formation of other stars in Chapter 30.

In the disk surrounding the young Sun, the temperature varied greatly with location. It was hottest close to the Sun, possibly as hot as 2000 K (1726°C), and coolest near the edge of the disk, far from the Sun. As the disk began to cool, different substances were able to condense into a liquid or solid form. One of the first elements to form would have been tungsten, because of its high condensing temperature. As the disk cooled further, more elements and compounds, such as aluminum oxide, iron, and silicates, were able to condense.

Eventually, the condensation of materials into liquid and solid forms slowed. The area closest to the Sun was still warm because of the Sun's proximity and energy, while at the outer edge of the disk, it was cold because the Sun was so distant. Thus, different elements and compounds were able to condense depending on their distance from the Sun, as illustrated in ***Figure 29-28,*** which impacted the compositions of the forming planets.

The Growth of Objects Once the condensing slowed, the tiny grains of condensed material started to accumulate and merge together to form larger bodies. These solid particles gradually built up in size as grains collided and stuck together, and as gas particles collected on the surfaces of the grains. As the solid bodies continued to grow, they eventually reached hundreds of kilometers in diameter. These objects are called **planetesimals.** Further growth continued through collisions and mergers of planetesimals. These events were violent and sometimes destroyed the planetesimals. However, the overall result was a smaller number of larger bodies: the planets.

Merging into Planets In the outer solar system, the first large planet to develop was Jupiter. As Jupiter increased in size through mergers of icy planetesimals, its gravity began to attract additional

NATIONAL GEOGRAPHIC

To learn more about The *Hubble Space Telescope,* go to the **National Geographic Expedition** on page 902.

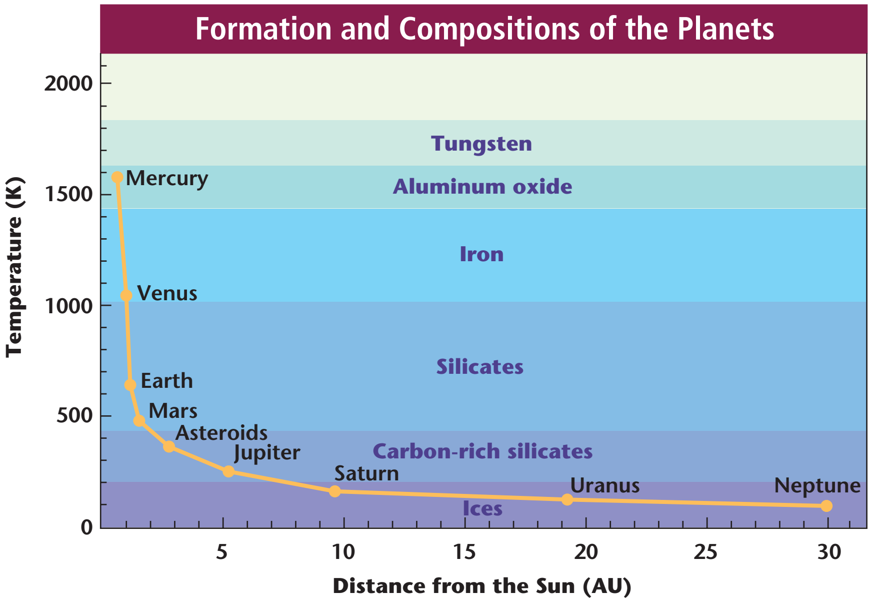


Figure 29-28 Elements and compounds that were able to condense close to the Sun, where it was warm, are called refractory elements, and far from the Sun, where it was cool, volatile elements could condense. Refractory elements, such as iron, comprise the terrestrial planets, which are close to the Sun. Volatile elements, such as ices and gases like hydrogen, comprise the planets farther from the Sun, where it is cool.

gas, dust, and planetesimals, so Jupiter grew even larger. Saturn and the other gas giants formed similarly, but they could not become as large because Jupiter had collected so much of the material in the vicinity. As each gas giant acquired material from its surroundings, a disk formed in its equatorial plane, much like the disk of the early solar system. In the disk, matter coalesced to form satellites.

In the inner part of the main disk, near the young Sun, planets also formed by the merging of planetesimals. These planetesimals, however, were composed primarily of refractory elements, so the inner planets are rocky and dense, in contrast to the gaseous outer planets. Also, the Sun's gravitational force is theorized to have swept up much of the gas in the area of the inner planets and prevented them from acquiring much additional material from their surroundings. Thus, the inner planets initially ended up with no satellites.

Earth Science Online

Update For an online update on our solar system, visit the Earth Science Web Site at earthgeu.com

Debris Eventually, the amount of interplanetary debris thinned out as it crashed into planets or was diverted out of the solar system. However, not all debris was ejected out of the solar system. The planetesimals in the area between Jupiter and Mars, known as the asteroid belt, remained there because Jupiter's gravitational force prevented them from merging to form a planet.

Asteroids

There are thousands and thousands of bodies that orbit the Sun within the planetary orbits. They are leftovers from the formation of the solar system and are called **asteroids.** Asteroids range from a

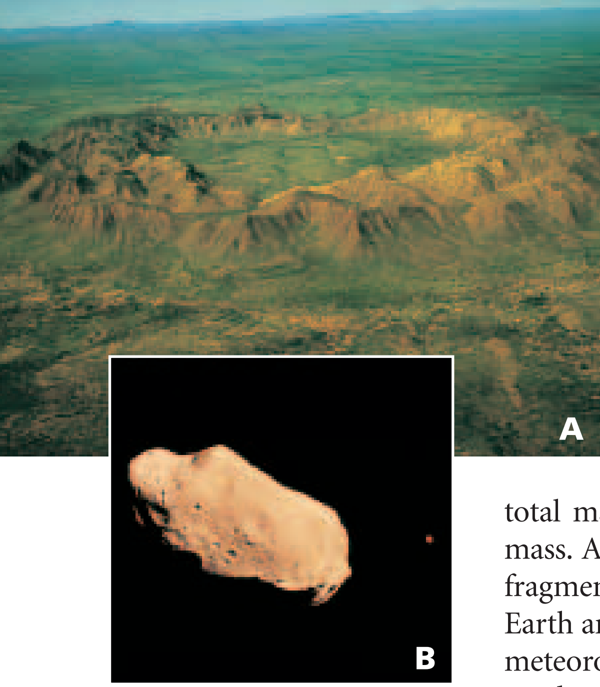


Figure 29-29 Gosses Bluff in central Australia **(A)** is 6 km in diameter and has a rim that is 200 m high. The asteroid Ida **(B),** photographed by *Galileo,* is 56 km in length and has its own moon, Dactyl.

few kilometers to about 1000 km in diameter and have pitted, irregular surfaces, like the surface of Ida, shown in ***Figure 29-29B.*** Most asteroids are located between the orbits of Mars and Jupiter within the asteroid belt.

Pieces of Asteroids The asteroids were once thought to represent planets that somehow had been destroyed. Today, however, they are thought to be leftover planetesimal pieces from the time of the solar system's formation that never formed planets. Astronomers estimate that the total mass of all the asteroids is only about 0.08 percent of Earth's mass. As the asteroids orbit, they occasionally collide and break into fragments. When this, or any, interplanetary material falls toward Earth and enters Earth's atmosphere, it is called a **meteoroid.** When a meteoroid falls toward Earth, it burns up in Earth's atmosphere and produces a streak of light called a **meteor.** If the meteoroid does not completely burn up, part of it will collide with the ground, and it is then called a **meteorite.** If the meteorite is large, it will cause an impact crater when it collides with the ground. There is evidence of impact craters on Earth, such as Meteor Crater in Arizona and Gosses Bluff in Central Australia, shown in ***Figure 29-29A.*** Any craters visible on Earth must be relatively young because otherwise they would have been erased by erosion.

COMETS

Other remnants from solar system formation are comets. **Comets** are small, icy bodies that have highly eccentric orbits around the Sun. Comets are made of ice and rock, and they range from 1 to 10 km in diameter. There are two clusters, or clouds, of comets: the Kuiper belt and the Oort cloud. The Kuiper belt is close to Pluto and is between 30 and 50 AU from the Sun. The Oort cloud lies more than 100 000 AU from the Sun. Occasionally, a comet is disturbed by the gravity of another object and is thrown into the inner solar system from one of these clusters.

Figure 29-30 Comet Hale-Bopp was visible in 1997, and it will not be visible again until the year 4397.

The Orbits of Comets Cometary orbits are highly eccentric. Some stretch far beyond the orbit of Pluto at aphelion, while others come very close to the Sun at perihelion. When a comet is within 3 AU of the Sun, it begins to evaporate, becomes much brighter, and forms a head and one or more tails. You may have seen the head and tails of comet Hale-Bopp, shown in ***Figure 29-30,*** when it lit up our night skies in the spring of 1997.

The head of a comet consists of the **coma** (KOH muh), an extended volume of glowing gas, and the **nucleus,** the small solid core, as shown in ***Figure 29-31.*** When the nucleus is heated, it releases gases and dust particles that form the coma and tails. The tails are pushed away from the coma by particles and ions coming from the Sun, as well as by the pressure of radiation from the Sun. This is why the tails of comets point away from the Sun, no matter what direction the comet is moving.

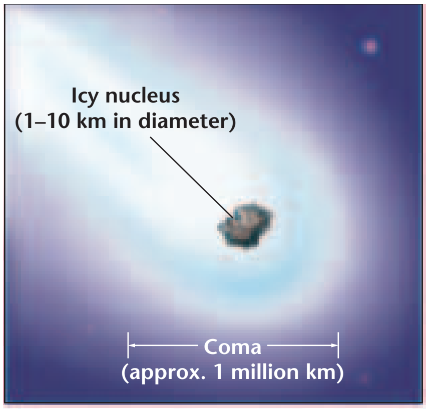


Figure 29-31 A comet consists of a nucleus, a coma, and tails pointing away from the Sun (not to scale).

Periodic Comets Comets that repeatedly orbit into the inner solar system are known as periodic comets. For example, Comet Halley is a well-known short-period comet with a 76-year period. Halley last appeared in 1985–1986, and it is expected again in 2061. Each time a periodic comet comes near the Sun, the Sun vaporizes some of the comet's ice, and the comet loses some of its matter. Eventually, it may break apart completely as the remaining ice evaporates.

When Earth intersects a cometary orbit, we experience a **meteor shower** as particles from the comet burn up upon entering Earth's upper atmosphere. Most meteors are caused by dust particles from comets, while most meteorites, the solid chunks of rock or metal that reach Earth's surface, are fragments of asteroids.

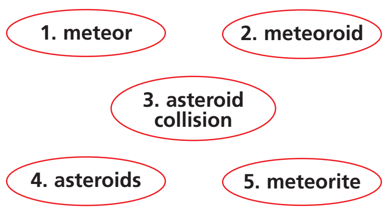
Astronomers theorize that solar system formation occurs commonly among stars. Thus, this has driven the search for planets and systems of planets orbiting other stars. You will learn more about these planets and their detection in the *Science in the News* feature at the end of this chapter.

SECTION ASSESSMENT

1. Explain why the material surrounding a young star forms a disk.
2. Describe why the inner planets are dense and rocky, while the outer planets have low densities and no solid surfaces.
3. Why is it theorized that the asteroids did not merge to form a planet?
4. For what reason did the inner planets not collect gas like the gas giants did?
5. **Thinking Critically** Why are there no comets in an orbit that is always close to the Sun?

SKILL REVIEW

6. **Concept Mapping** Use the following terms to construct a concept map to organize the correct sequence of events. For more help, refer to the *Skill Handbook.*



DESIGN YOUR OWN GeoLab

Scaling the Solar System

Astronomers are familiar with both the small, such as interstellar dust particles, and the large, such as the solar system. In order to understand the variety of sizes in the solar system, astronomers use models. These models can be as simple as putting people or objects in marked places or as complex as elaborate computer simulations. The most difficult task with many models is choosing a scale that will display all the information needed, such as distance, rotation rates, and size.

Preparation

Problem

How can the size of the solar system be converted to a scale that will easily demonstrate relative distances between objects in the solar system? Is distance the only measurement that can be demonstrated in a scale model?

Possible Materials

calculator
meterstick
marker
variety of sizes of common round objects
tape measure
stopwatches
masking tape

Hypothesis

Brainstorm about possible models and data needed to create them. Determine where these data are available, and collect them to use as a reference for your model. To have your model fit in your chosen area, make a hypothesis about the appropriate scale to use for distance from the Sun to each planet. Hypothesize how additional solar system measurements can be included in your model. For example, think about including planet diameters, rotation rates, etc.

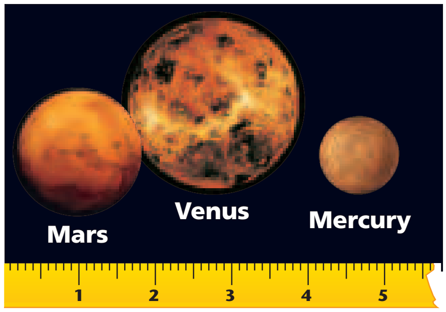
Objectives

In this GeoLab, you will:

- **Calculate** the distance from the Sun for each planet based on your scale.
- **Determine** how to incorporate additional solar system measurements into your model, or design another model to show that information.
- **Interpret** your results based on your scale, and decide if your scale was an appropriate one based on the problems that may have resulted.

Plan the Experiment

1. As a group, make a list of possible ways you might test your hypotheses. Keep the available materials in mind as you plan your procedure.
2. Be sure your scale is appropriate for the information you are representing. Remember that a model should have the same scale throughout. You may have to try more than one scale before you are successful.
3. Record your procedure and list every step. Determine what materials are needed and the amounts of each.
4. Design and construct a data table for recording your original data and your scaled data.
5. Check the plan. Make sure your teacher has approved your plan before you proceed with your experiment.
6. Carry out your plan.



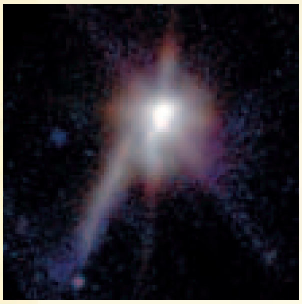
Analyze

1. **Checking Your Hypothesis** Which scale worked the best for your model? Explain.
2. **Interpreting Observations** What problems did you have in finding a scale? Explain how you corrected the problems.
3. **Calculating Results** List and explain the conversions that you used to create your scale model. If multiple steps were necessary to convert to your scale units, how could they be combined to make the process simpler?
4. **Observing and Inferring** What possible problems could result from using a very large scale? A small scale? Explain why depicting a scale model of the solar system on a sheet of notebook paper is extremely difficult.
5. **Compare and Contrast** Compare and contrast your model with one of your classmates'. What were the advantages of the scale you used? What were the disadvantages? How would you improve your model?
6. **Thinking Critically** Suppose that the outer planets are three times farther away than they are now. How would this affect your model? What scale would you choose now? Explain.

Conclude & Apply

1. Proxima Centauri, the closest star to our Sun, is about 4.01×10^{13} km from the Sun. Based on your scale, how far would Proxima Centauri be from the Sun in your model? If you were to fit the distance between the Sun and Proxima Centauri into your classroom, how small would the scaled distance between Pluto and the Sun be?
2. An interstellar dust particle is 1.0×10^{-6} m in length. Convert this measurement to your scale. How many dust particles could fit in the distance between the Sun and Jupiter? Between Mars and Uranus?

Science in the News



Discovering New Planets

Have you ever looked up at the night sky and wondered whether there are other Earth-like planets? We know that there are other stars similar to the Sun in the galaxy. In 1995 the first evidence of a planet was discovered.

In 1995, after a year of careful measurements, Swiss astronomers announced the discovery of a planet orbiting around the star 51 Pegasi. A planet found outside of our solar system is called an extrasolar planet. Shortly after the discovery of the first extrasolar planet, several more were discovered. More than 100 extrasolar planets have been detected, with the number of discoveries increasing with every passing month.

Detecting Planets

The presence of these extrasolar planets was inferred, not directly detected. The gravitational attraction of a star and a planet causes both bodies to orbit around a center of mass. Because the star is much larger and brighter than the planet, astronomers actually detect the small movement of the star around the center of mass, rather than directly observing the planet. Then, by using Newton's law of universal gravitation, astronomers can determine information such as the planet's minimum mass and orbital period.

In addition to single planets orbiting around stars, astronomers have found more than one planet orbiting around a single star. On April 15, 1999, astronomers announced the discovery of three planets orbiting around the star Upsilon Andromedae. This discovery was significant because scientists then had evidence of a multiple-planet system, similar to our solar system with its nine planets. On March 29, 2000, two planets smaller than Saturn were discovered. Until this time, only larger planets close to the size of Jupiter had been discovered.

Direct Evidence?

In the fall of 1999, astronomers using Earth-based telescopes recorded the distinct dimming of light from a star in the constellation Pegasus. Previously, a planet had been inferred from gravitational effects, but astronomers did not have direct evidence. However, the dimming occurred where the gravitational effects predicted the planet to be. This dimming was caused by the light from the star being blocked out by an extrasolar planet passing in front of the star. This provided direct evidence of an extrasolar planet.

No Earth-sized planets have yet been discovered, but scientists theorize that they exist. Two NASA missions, the *Space Interferometry Mission (SIM)* and the *Terrestrial Planet Finder Mission (TPF),* will be used to study the extrasolar planets. *SIM* will have special telescopes that will be able to detect Earth-sized extrasolar planets. Later, the *TPF* will be used to study the compositions of the atmospheres and surfaces of the planets.

Activity

Visit your library or the Earth Science Web Site at earthgeu.com to research the most recent extrasolar planet discoveries. Present your findings to the class on a poster or in an oral report.

CONTENTS

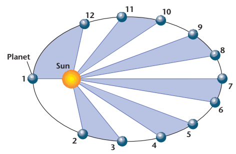
CHAPTER 29

Study Guide

Summary

SECTION 29.1

Overview of Our Solar System



Main Ideas

- Early astronomers explained the motions of the planets with geocentric models, including epicycles.
- Copernicus, Brahe, Kepler, and Galileo developed evidence supporting a heliocentric solar system model.
- Newton developed a law of gravitation that was used to demonstrate the validity of the heliocentric model.

Vocabulary

aphelion (p. 777)
astronomical unit (p. 777)
eccentricity (p. 777)
perihelion (p. 777)
retrograde motion (p. 776)

SECTION 29.2

The Terrestrial Planets

Main Ideas

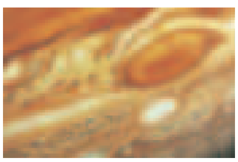
- The terrestrial planets include the four planets closest to the Sun. They are relatively small and dense, and they have rocky surfaces.
- Mercury has a surface similar to the Moon's, but a very different interior.
- Venus has an extremely hot surface as a result of greenhouse heating, but is similar to Earth in other properties.
- Earth is suitable for life because of its unique orbital position that allows water to exist in all three phases on the surface.
- Mars shows signs of having once had tectonic activity.

Vocabulary

gas giant planet (p. 780)
precession (p. 783)
terrestrial planet (p. 780)

SECTION 29.3

The Gas Giant Planets



Main Ideas

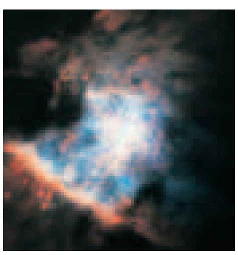
- The gas giant planets are very large and have low densities, no solid surfaces, ring systems, and many moons.
- Jupiter is the largest of the planets. It has a fluid interior, except for a small rocky core, and several moons. Saturn is slightly smaller than Jupiter and has a more extensive ring system.
- Uranus and Neptune are very similar in size and composition.
- Pluto is not classified as a gas giant or a terrestrial planet.

Vocabulary

belt (p. 787)
liquid metallic hydrogen (p. 787)
zone (p. 787)

SECTION 29.4

Formation of Our Solar System



Main Ideas

- The solar system formed from a collapsing interstellar cloud that flattened into a disk from which the planets formed.
- Terrestrial planets formed from refractory materials in the hot inner disk, and gas giants formed from volatile elements in the cold outer disk.
- Asteroids are rocky remnants of the early solar system. Most of them orbit the Sun between Mars and Jupiter.
- Comets have highly eccentric orbits and are made of rock and ice. When they are close to the Sun, they glow brightly and have a head and tails of gas and dust.

Vocabulary

asteroid (p. 795)
coma (p. 797)
comet (p. 796)
meteor (p. 796)
meteor shower (p. 797)
meteorite (p. 796)
meteoroid (p. 796)
nucleus (p. 797)
planetesimal (p. 794)

earthgeu.com/vocabulary_puzzlemaker

CHAPTER 29 Assessment

Understanding Main Ideas

1. What is a planet's backward motion in the sky called?
a. revolving
b. retrograde motion
c. planetary spin
d. geocentric motion

2. What point in a planet's orbit is closest to the Sun?
a. focus
b. semimajor axis
c. aphelion
d. perihelion

3. What model of our solar system did Copernicus propose?
a. a heliocentric model
b. a retrograde model
c. a geocentric model
d. a nested-sphere model

4. A planet's average distance from the Sun is also what part of the orbital ellipse?
a. the distance between the foci
b. the eccentricity
c. the semimajor axis
d. the circumference

5. How were the plains on Mercury hypothesized to have formed?
a. from large oceans smoothing out the surface
b. from lava flows
c. from wind eroding high points
d. from landslides on the scarps

6. Why does the Sun rise in the west and set in east when viewed from Venus?
a. Venus is the closest planet to Earth.
b. Venus has a retrograde rotation.
c. Venus's orbital period is 224 Earth days.
d. The semimajor axis of Venus is only 0.723 AU from the Sun.

7. What two planets have similar appearances, atmospheric compositions, interiors, and particle belts?
a. Neptune and Uranus
b. Mars and Venus
c. Saturn and Neptune
d. Saturn and Uranus

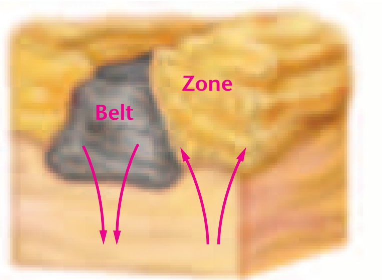
8. Which condensed into solid form closest to the Sun?
a. refractory elements
b. volatile elements
c. gas giants
d. the Oort cloud

9. What does Kepler's third law state?

10. Which planet is not classified as a gas giant or a terrestrial planet? Why?

11. Why is the surface temperature of Venus 750 K (476°C)?

Use the diagram below to answer question 12.



12. Identify a belt and a zone. What is the direction of movement of each?

Test-Taking Tip

MNEMONICS Use memory devices to help you remember terms and orders. For example, My Very Elegant Monkey Just Sat Upon Nancy's Petunias can help you remember the order of the planets in our solar system.

CHAPTER 29 Assessment

13. If the Martian atmosphere is 95 percent carbon dioxide, why doesn't Mars have a strong greenhouse effect?
14. Where are asteroids hypothesized to have originated?
15. What new discovery was made from the *Voyager 1* and *Voyager 2* visits to Jupiter?
16. What does the density of Pluto indicate that it is made of?

Applying Main Ideas

17. What were some of the advantages of the Sun-centered model proposed by Copernicus?
18. How are Venus and Earth similar, and how are they different?
19. How has Jupiter's gravitational force affected the geology of its four major moons?
20. What are the differences between asteroids and comets?
21. How did collisions during the formation of the planets affect Earth, Mercury, Venus, and Uranus?
22. Would it be possible for a gas giant to form close to the Sun? Explain.
23. How are the rings of the gas giants theorized to have formed?

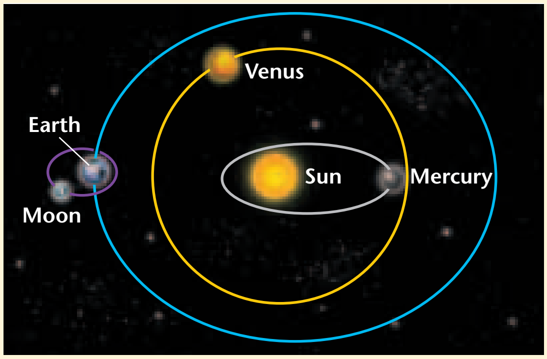
Thinking Critically

24. Why are the volcanoes on Mars so much larger than those on Earth?
25. Why are the rings of each gas giant planet closer to the planet than its large moons are?
26. Should Pluto be considered a planet or a planetesimal? Explain.
27. How would a circular orbit affect Kepler's second and third laws? Restate these laws using the radius of a circle.

Standardized Test Practice

Interpreting Scientific Illustrations

Use the diagram below to answer questions 1 and 2.



1. Which planet is located at aphelion in its orbit?
   a. Mercury **c.** Earth
   b. Venus **d.** none of the above

2. Which orbit shown has an eccentricity that is closest to 0?
   a. Mercury **c.** Earth
   b. Venus **d.** the Moon

3. How are Mercury and the Moon similar?
   a. Both are covered with craters and plains.
   b. Both have the same night-day temperature difference.
   c. They have the same strength of surface gravity.
   d. Both have an extensive nickel-iron core.

4. What is a piece of interplanetary material that burns up in Earth's atmosphere called?
   a. a meteorite **c.** a meteor
   b. an asteroid **d.** a meteoroid

earthgeu.com/standardized_test