CHAPTER 28 Our Solar System

BIG Idea Using the laws of motion and gravitation, astronomers can understand the orbits and the properties of the planets and other objects in the solar system.

28.1 Formation of the Solar System

MAIN Idea The solar system formed from the collapse of an interstellar cloud.

28.2 The Inner Planets

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

28.3 The Outer Planets

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

28.4 Other Solar System Objects

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

GeoFacts

- It is likely that Jupiter was the first planet in the solar system to form.
- It rains sulfuric acid on Venus.
- Mercury's days are two-thirds the length of its years.

Jupiter's Great Red Spot
Voyager 2 flyby

Jupiter
Hubble Space Telescope

Jupiter and moons
Low-power, Earth-based telescope

(t)NASA/JPL-Caltech, (c)Amy Simon/Reta Beebe/Heidi Hammel/NASA, (b)John Chumack/Photo Researchers, (bkgd)Astrofoto/Peter Arnold, Inc.

LAUNCH Lab

What can be learned from space missions?

Most of the planets in our solar system have been explored by uncrewed space probes. You can learn about these missions and their discoveries by using a variety of resources. Both the agencies that sponsor missions and the scientists involved usually provide extensive information about the design, operation, and scientific goals of the missions.

Procedure

1. Read and complete the lab safety form.
2. Go to glencoe.com and find information on missions to four different planets.
3. Draw a table listing some of the key aspects of 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.

Analysis

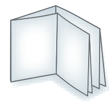
1. **Summarize** in a table what scientists learned from each mission or what they hope to learn.
2. **Determine** which missions are still in progress, which ones have gone beyond their mission life, and which ones have been completed.
3. **Suggest** other missions that could be conducted in the future.

FOLDABLES™ Study Organizer

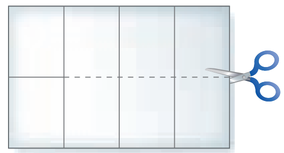
The Planets Make the following Foldable that features the planets of our solar system.

STEP 1 Fold a sheet of paper in half.

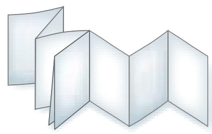
STEP 2 Fold in half and then in half again to form eight sections.



STEP 3 Cut along the long fold line, stopping before you reach the last two sections.



STEP 4 Refold the paper into an accordion book. You might want to glue the double pages together.



FOLDABLES **Use this Foldable with Sections 28.1, 28.2, and 28.3.** As you read these sections, summarize the main characteristics of the planets.

Earth Science Online

Visit glencoe.com to

- study entire chapters online;
- explore Concepts In Motion animations:
  - Interactive Time Lines
  - Interactive Figures
  - Interactive Tables
- access Web Links for more information, projects, and activities;
- review content with the Interactive Tutor and take Self-Check Quizzes.

Section 28.1

Formation of the Solar System

Objectives

- **Explain** how the solar system formed.
- **Describe** early concepts of the structure of the solar system.
- **Describe** how our current knowledge of the solar system developed.
- **Relate** gravity to the motions of the objects in the solar system.

Review Vocabulary

focus: one of two fixed points used to define an ellipse

New Vocabulary

planetesimal
retrograde motion
ellipse
astronomical unit
eccentricity

MAIN Idea The solar system formed from the collapse of an interstellar cloud.

Real-World Reading Link If you have ever made a snowman by rolling a snowball over the ground, you have demonstrated how planets formed from tiny grains of matter.

Formation Theory

Theories of the origin of the solar system rely on direct observations and data from probes. Scientific theories must explain observed facts, such as the shape of the solar system, differences among the planets, and the nature of the oldest planetary surfaces—asteroids, meteorites, and comets.

A Collapsing Interstellar Cloud

Stars and planets form from interstellar clouds, which exist in space between the stars. These clouds consist mostly of hydrogen and helium gas with small amounts of other elements and dust. Dust makes interstellar clouds look dark because it blocks the light from stars within or behind the clouds. Often, starlight reflects off of the dust and partially illuminates the clouds. Also, stars can heat clouds, making them glow on their own. This is why interstellar clouds often appear as blotches of light and dark, as shown in **Figure 28.1.** This interstellar dust can be thought of as a kind of smog that contains elements formed in older stars, which expelled their matter long ago.

At first, the density of interstellar gas is low—much lower than the best vacuums created in laboratories. However, gravity slowly draws matter together until it is concentrated enough to form a star and possibly planets. Astronomers think that the solar system began this way. They have also observed planets around other stars, and hope that studying such planet systems will provide clues to how our solar system formed.

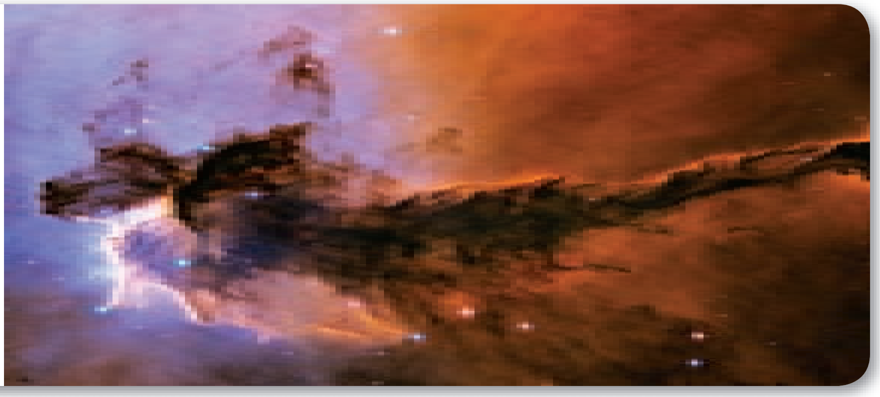
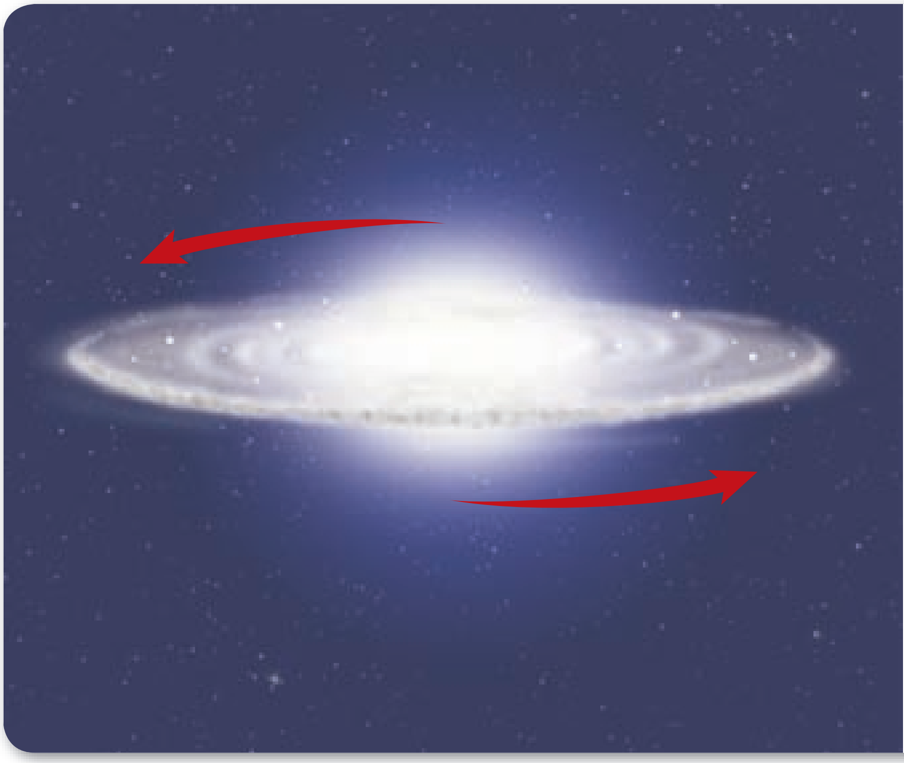


Figure 28.1 Stars form in collapsing interstellar clouds, such as in the Eagle nebula, pictured here.



■ **Figure 28.2** The interstellar cloud that formed our solar system collapsed into a rotating disk of dust and gas. When concentrated matter in the center acquired enough mass, the Sun formed in the center and the remaining matter gradually condensed, forming the planets.

Collapse accelerates At first, the collapse of an interstellar cloud is slow, but it gradually accelerates and the cloud becomes much denser at its center. If rotating, the cloud spins faster as it contracts, for the same reason that ice skaters spin faster as they pull their arms close to their bodies—centripetal force. As the collapsing cloud spins, the rotation slows the collapse in the equatorial plane, and the cloud becomes flattened. Eventually, the cloud becomes a rotating disk with a dense concentration of matter at the center, as shown in **Figure 28.2.**

Reading Check **Explain** why the rotating disk spins faster as it contracts.

Vocabulary

Academic vocabulary

Collapse
to fall down, give way, or cave in
The hot-air balloon collapsed when the fabric was torn.

Matter condenses Astronomers think our solar system began in this manner. The Sun formed when the dense concentration of gas and dust at the center of a rotating disk reached a temperature and pressure high enough to fuse hydrogen into helium. The rotating disk surrounding the young Sun became our solar system. Within this disk, the temperature varied greatly with location; the area closest to the dense center was still warm, while the outer edge of the disk was cold. This temperature gradient resulted in different elements and compounds condensing, depending on their distance from the Sun. This also affected the distribution of elements in the forming planets. The inner planets are richer in the higher melting point elements and the outer planets are composed mostly of the more volatile elements. That is why the outer planets and their moons consist mostly of gases and ices. Eventually, the condensation of materials into liquid and solid forms slowed.

NATIONAL GEOGRAPHIC To read more about ways that astronomers are studying the formation of the solar system, go to the **National Geographic Expedition** on page 934.

Concepts In Motion

Interactive Table To explore more about the planets, visit glencoe.com.

Table 28.1 Physical Data of the Planets

Planet	Diameter (km)	Relative Mass (Earth = 1)	Average Density (g/cm^3)	Atmosphere	Distance from the Sun (AU)	Moons
Mercury	4,880	0.06	5.43	none	0.39	0
Venus	12,104	0.821	5.20	CO_2, N_2	0.72	0
Earth	12,742	1.00	5.52	N_2, O_2, H_2O	1.00	1
Mars	6,778	0.21	3.93	CO_2, N_2, Ar	1.52	2
Jupiter	139,822	317.8	1.33	H_2, He	5.2	63
Saturn	116,464	95.2	0.69	H_2, He	9.58	47
Uranus	50,724	14.5	1.27	H_2, He, CH_4	19.2	27
Neptune	49,248	17.1	1.64	H_2, He, CH_4	30.04	13

Planetesimals

Next, the tiny grains of condensed material started to accumulate and merge, forming larger particles. These particles grew as grains collided and stuck together and as gas particles collected on their surfaces. Eventually, colliding particles in the early solar system merged to form **planetesimals**—objects hundreds of kilometers in diameter. Growth continued as planetesimals collided and merged. Sometimes, collisions destroyed planetesimals, but the overall result was a smaller number of larger bodies—the planets. Their properties are given in **Table 28.1.**

FOLDABLES Incorporate information from this section into your Foldable.

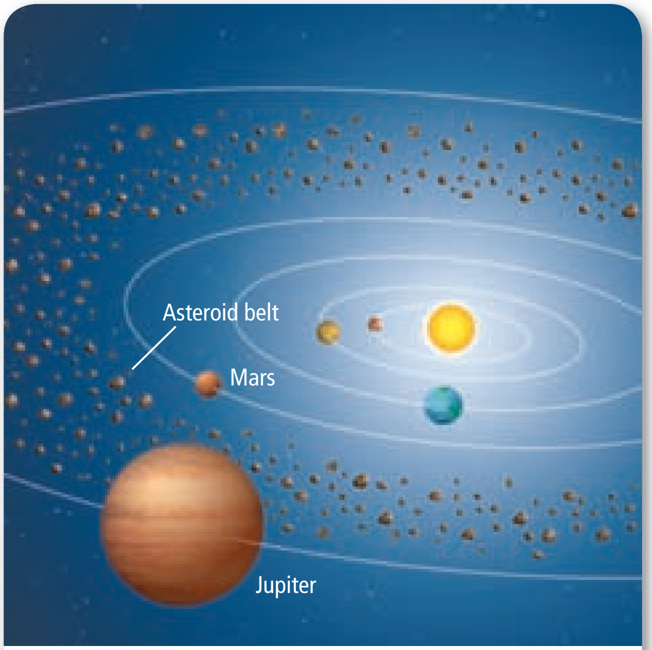
Gas giants form The first large planet to develop was Jupiter. Jupiter increased in size through the merging of icy planetesimals that contained mostly lighter elements. It grew larger as its gravity attracted additional gas, dust, and planetesimals. Saturn and the other gas giants formed similarly, but they could not become as large because Jupiter had collected so much of the available material. As each gas giant attracted material from its surroundings, a disk formed in its equatorial plane, much like the disk of the early solar system. In this disk, matter clumped together to form rings and satellites.

CAREERS IN EARTH SCIENCE

Planetologist A planetologist applies the theories and methods of sciences, such as physics, chemistry, and geology, as well as mathematics, to study the origin, composition, and distribution of matter in planetary systems. To learn more about Earth science careers, visit glencoe.com.

Terrestrial planets form Planets also formed by the merging of planetesimals in the inner part of the main disk, near the young Sun. These were composed primarily of elements that resist vaporization, so the inner planets are rocky and dense, in contrast to the gaseous outer planets. Also, scientists think that the Sun's gravitational force swept up much of the gas in the area of the inner planets and prevented them from acquiring much of this material from their surroundings. Thus, the inner planets did not develop satellites.

Debris Material that remained after the formation of the planets and satellites is called debris. Eventually, the amount of interplanetary debris diminished as it crashed into planets or was diverted out of the solar system. Some debris that was not ejected from the solar system became icy objects known as comets. Other debris formed rocky planetesimals known as asteroids. Most asteroids are found in the area between Jupiter and Mars known as the asteroid belt, shown in **Figure 28.3.** They remain there because Jupiter's gravitational force prevented them from merging to form a planet.



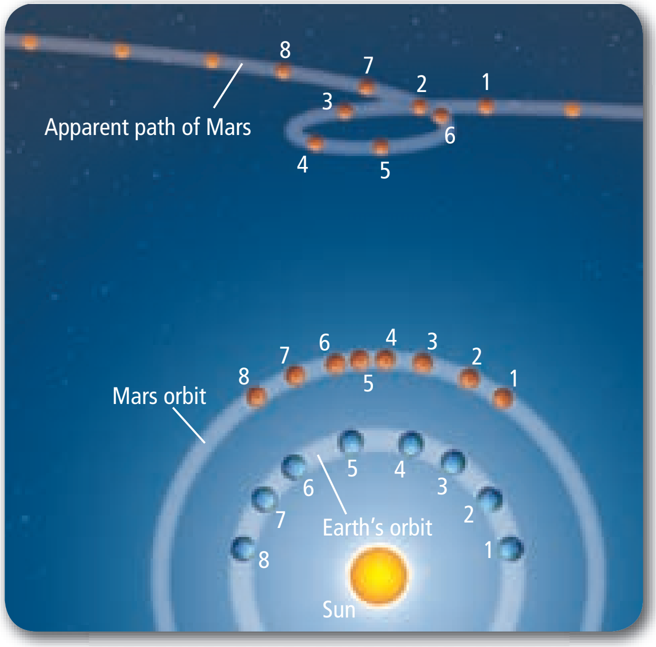
■ **Figure 28.3** Thousands of asteroids have been detected in the asteroid belt, which lies between Mars and Jupiter.

Modeling the Solar System

Ancient astronomers assumed that the Sun, planets, and stars orbited a stationary Earth in an Earth-centered model of the solar system. They thought this explained the most obvious daily motion of the stars and planets rising in the east and setting in the west. But as you learned in Chapter 27, this does not happen because these bodies orbit Earth, but rather that Earth spins on its axis.

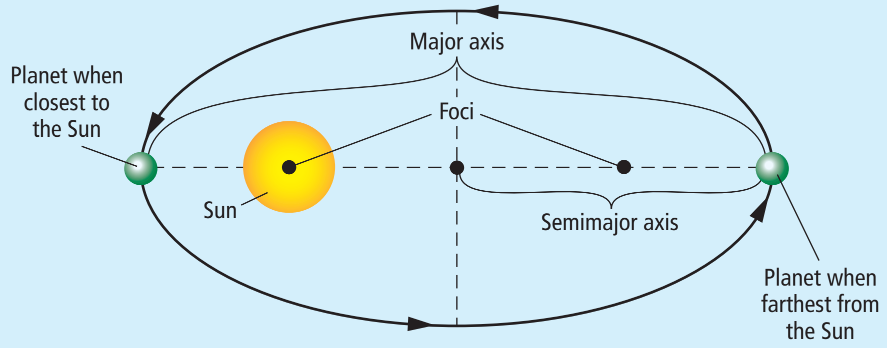
This geocentric (jee oh SEN trihk), or Earth-centered, model could not readily explain some other aspects of planetary motion. For example, the planets might appear farther to the east one evening, against the background of the stars, than they had the previous night. Sometimes a planet seems to reverse direction and move back to the west. The apparent backward movement of a planet is called **retrograde motion.** The retrograde motion of Mars is shown in the time-lapse image and diagram in **Figure 28.4.** The search for a simple explanation of retrograde motion motivated early astronomers to keep searching for a better explanation for the design of the solar system.

■ **Figure 28.4** This composite of images taken at ten-day intervals shows the apparent retrograde motion of Mars. The diagram shows how the changing angles of view from Earth create this effect.



TunÁ Tezel

■ **Figure 28.5** This diagram shows the geometry of an ellipse using an exaggerated planetary orbit. The Sun lies at one of the two foci. The minor axis of the ellipse is its shorter diameter. The major axis of the ellipse is its longer diameter, which equals the distance between a planet's closest and farthest points from the Sun. Half of the semimajor axis represents the average distance of the planet to the Sun.



Heliocentric model In 1543, Polish scientist Nicolaus Copernicus suggested that the Sun was the center of the solar system. In this Sun-centered, or heliocentric (hee lee oh SEN trihk) model, Earth and all the other planets orbit the Sun. In a heliocentric model, the increased gravity of proximity to the Sun causes the inner planets to move faster in their orbits than do the outer planets. It also provided a simple explanation for retrograde motion.

Kepler's first law Within a century, the ideas of Copernicus were confirmed by other astronomers, who found evidence that supported the heliocentric model. For example, Tycho Brahe (TIE coh BRAH), a Danish astronomer, designed and built very accurate equipment for observing the stars. From 1576–1601, before the telescope was used in astronomy, he made accurate observations to within a half arc minute of the planets' positions. Using Brahe's data, German astronomer Johannes Kepler demonstrated that each planet orbits the Sun in a shape called an ellipse, rather than a circle. This is known as Kepler's first law of planetary motion. 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 (singular, focus). The major axis is the line that runs through both foci at the maximum diameter of the ellipse, as illustrated in **Figure 28.5.**

VOCABULARY
SCIENCE USAGE V. COMMON USAGE
Law
Science usage: a general relation proved or assumed to hold between mathematical expressions

Common usage: a rule of conduct prescribed as binding and enforced by a controlling authority

Reading Check **Describe** the shape of planetary orbits.

Each planet has its own elliptical orbit, but the Sun is always at one focus. For each planet, the average distance between the Sun and the planet is its semimajor axis, which equals half the length of the major axis of its orbit, as shown in **Figure 28.5.** Earth's semimajor axis is of special importance because it is a unit used to measure distances within the solar system. Earth's average distance from the Sun is 1.496×10^8 km, or 1 **astronomical unit** (AU).

Eccentricity A planet in an elliptical orbit does not orbit at a constant distance from the Sun. 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. You will investigate this ratio in the MiniLab. The orbits of most planets are not very eccentric; in fact, some are almost perfect circles.

The eccentricity of a planet can change slightly. Earth's eccentricity today is about 0.02, but the gravitational attraction of other planets can stretch the eccentricity to 0.05, or cause it to fall to 0.01.

Kepler's second and third laws In addition to discovering the shapes of planetary orbits, Kepler showed that planets move faster when they are closer to the Sun. He demonstrated this by proving that an imaginary line between the Sun and a planet sweeps out equal amounts of area in equal amounts of time, as shown in **Figure 28.6.** This is known as Kepler's second law.

The length of time it takes for a planet or other body to travel a complete orbit around the Sun is called its orbital period. In Kepler's third law of planetary motion, he determined the mathematical relationship between the size of a planet's ellipse and its orbital period. This relationship is written as follows:

$$P^2 = a^3$$

P is time measured in Earth years, and *a* is length of the semimajor axis measured in astronomical units.

MiniLab

Explore Eccentricity

How is eccentricity of an ellipse calculated? Eccentricity is the ratio of the distance between the foci to the length of the major axis. Eccentricity ranges from 0 to 1; the larger the eccentricity, the more extreme the ellipse.

Procedure

WARNING: *Use caution when handling sharp objects.*

1. Read and complete the lab safety form.
2. Tie a piece of **string** to form a circle that will fit on a piece of **cardboard.**
3. Place a sheet of **paper** on the cardboard.
4. Stick two **pins** in the paper a few centimeters apart and on a line that passes through the center point of the paper.
5. Loop the string over the pins, and keeping the string taut, use a pencil to trace an ellipse around the pins.
6. Use a **ruler** to measure the major axis and the distance between the pins. Calculate the eccentricity.

Analysis

1. **Identify** what the two pins represent.
2. **Explain** how the eccentricity changes as the distance between the pins changes.
3. **Predict** the kind of figure formed and the eccentricity if the two pins were at the same location.

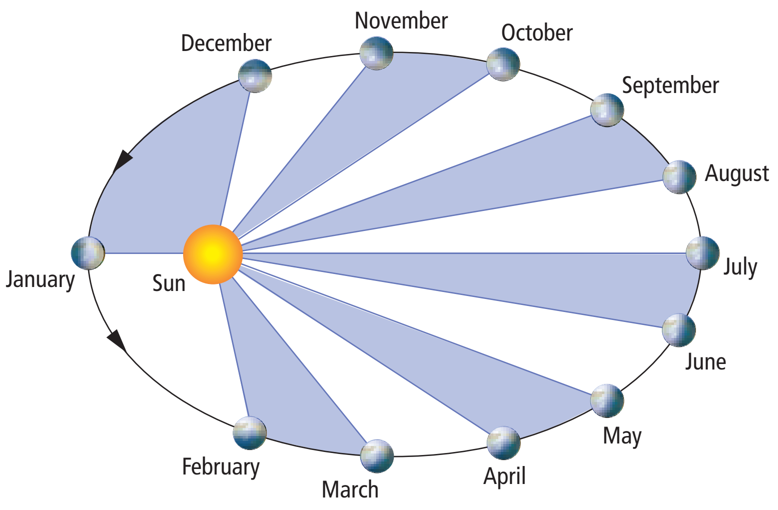


Figure 28.6 Kepler's second law states that planets move faster when close to the Sun and slower when farther away. This means that a planet sweeps out equal areas in equal amounts of time. (Note: *not drawn to scale*)

■ **Figure 28.7** Galileo would probably be astounded to see Jupiter's moons in the composite image above. Still, his view of Jupiter and its moons proved a milestone in support of heliocentric theory.

NASA

Galileo 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 discoveries that supported Copernicus's ideas. The most famous of these was his discovery that four moons orbit the planet Jupiter, proving that not all celestial bodies orbit Earth, and demonstrating that Earth was not necessarily the center of the solar system. Galileo's view of Jupiter's moons, similar to the chapter opener photo, is compared with our present-day view of them, shown in **Figure 28.7.** The underlying explanation for the heliocentric model remained unknown until 1684, when English scientist Isaac Newton published his law of universal gravitation.

Gravity

Newton first developed an understanding of gravity by observing falling objects. He described falling as downward acceleration produced by gravity, an attractive force between two objects. He determined that both the masses of and the distance between two bodies determined the force between them. This relationship is expressed in his law of universal gravitation, illustrated in **Figure 28.8,** and that is stated mathematically as follows:

$$F = \frac{Gm_1m_2}{r^2}$$

F is the force measured in newtons, G is the universal gravitation constant (6.6726×10^{-11} m^3/ kg·s^2), m_1 and m_2 are the masses of the bodies in kilograms, and r is the distance between the two bodies in meters.

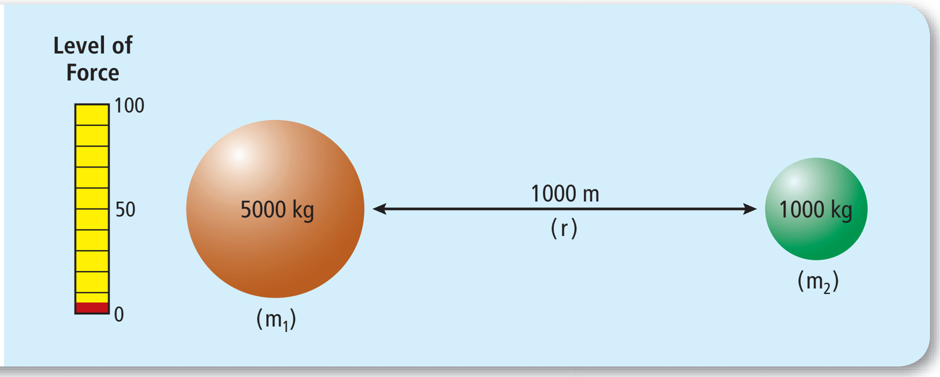
Gravity and orbits Newton realized that this attractive force could explain why planets move according to Kepler's laws. He observed the Moon's motion and realized that its direction changes because of the gravitational attraction of Earth. In a sense, the Moon is constantly falling toward Earth. If it were not for this attraction, the Moon would continue to move in a straight line and would not orbit Earth. The same is true of the planets and their moons, stars, and all orbiting bodies throughout the universe.

Concepts In Motion

Interactive Figure To see an animation of gravitational attraction, visit glencoe.com.

■ **Figure 28.8** The gravitational attraction between these two objects is 5.0×10^{-10} N.

Predict *the effect of doubling the masses of both objects, and check your prediction using Newton's equation.*



Center of mass Newton also determined that each planet orbits a point between it and the Sun called the center of mass. For any planet and the Sun, the center of mass is just above or within the surface of the Sun, because the Sun is much more massive than any planet. **Figure 28.9** shows how this is similar to the balance point on a seesaw.

Present-Day Viewpoints

Astronomers traditionally divided the planets into two groups: the four smaller, rocky, inner planets, Mercury, Venus, Earth, and Mars; and the four outer gas planets, Jupiter, Saturn, Uranus, and Neptune. It was not clear how to classify Pluto, because it is different from the gas giants in composition and orbit. Pluto also did not fit the present-day theory of how the solar system developed. Then in the early 2000s, astronomers discovered a vast number of small, icy bodies inhabiting the outer reaches of the solar system, thousands of AU beyond the orbit of Neptune. At least one of these is larger than Pluto.

These discoveries have led many astronomers to rethink traditional views of the solar system. Some already define it in terms of three zones: Zone 1, Mercury, Venus, Earth, Mars; Zone 2, Jupiter, Saturn, Uranus, Neptune; and Zone 3, everything else, including Pluto. In science, views change as new data becomes available and new theories are proposed. Astronomy today is a rapidly changing field.

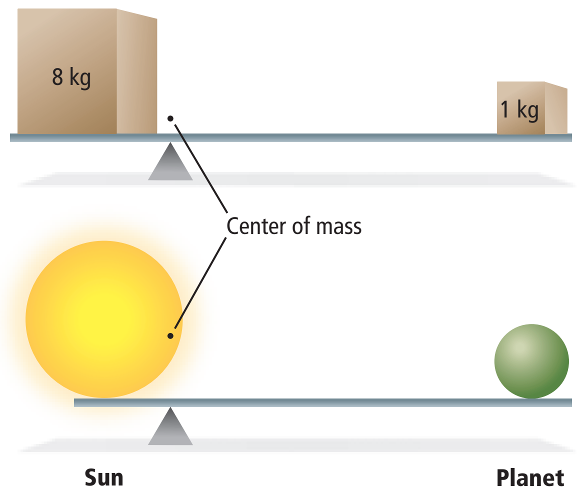


Figure 28.9 Just as the balance point on a seesaw is closer to the heavier box, the center of mass between two orbiting bodies is closer to the more massive body.

Section 28.1 Assessment

Section Summary

- A collapsed interstellar cloud formed the Sun and planets from a rotating disk.
- The inner planets formed closer to the Sun than the outer planets, leaving debris to produce asteroids and comets.
- Copernicus created the heliocentric model and Kepler defined its shape and mechanics.
- Newton explained the forces governing the solar system bodies and provided proof for Kepler's laws.
- Present-day astronomers divide the solar system into three zones.

Understand Main Ideas

1. MAIN Idea **Describe** the formation of the solar system.
2. **Explain** why retrograde motion is an apparent motion.
3. **Describe** how the gravitational force between two bodies is related to their masses and the distance between them.
4. **Compare** the shape of two ellipses having eccentricities of 0.05 and 0.75.

Think Critically

5. **Infer** Based on what you have learned about Kepler's third law, which planet moves faster in its orbit: Jupiter or Neptune? Explain.

MATH in Earth Science

6. Use Newton's law of universal gravitation to calculate the force of gravity between two students standing 12 m apart. Their masses are 65 kg and 50 kg.

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.

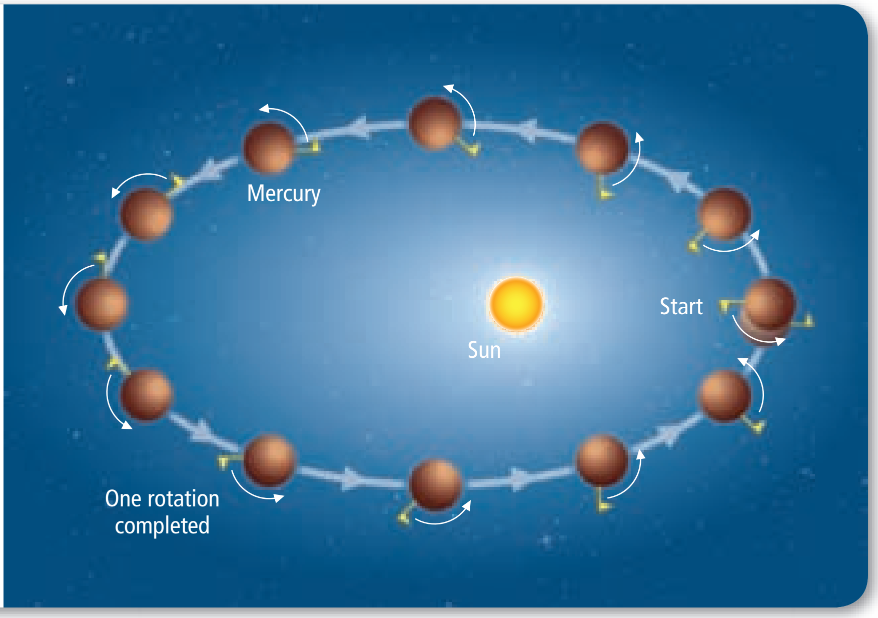


Figure 28.10 Because of Mercury's odd rotation, its day lasts for two-thirds of its year. **Compare** *Mercury's orbital motion with that of Earth's Moon.*

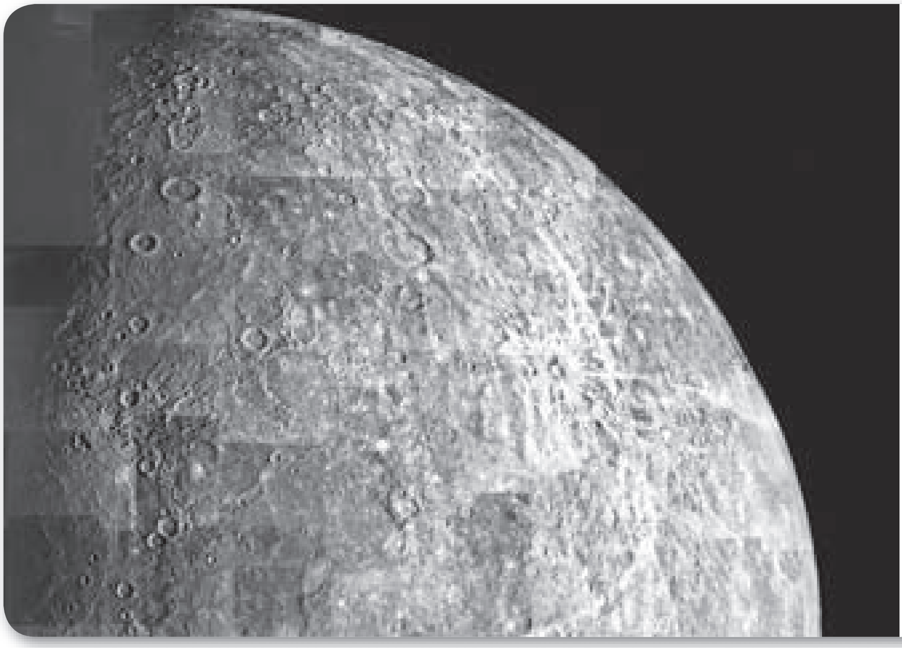


Figure 28.11 This mosaic of Mercury's heavily cratered surface was made by *Mariner 10.* Craters range in size from 100 to 1300 km in diameter.

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.

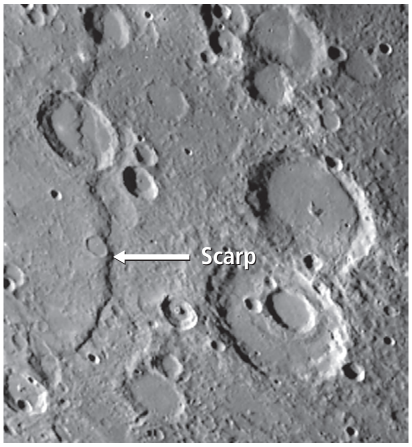
Surface Most knowledge about Mercury is based on the radio observations from Earth, and images from U.S. space probe *Mariner 10,* which passed close to Mercury three times in 1974 and 1975. Images from *Mariner 10* show that Mercury's surface, like that of the Moon, is covered with craters and plains, 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.

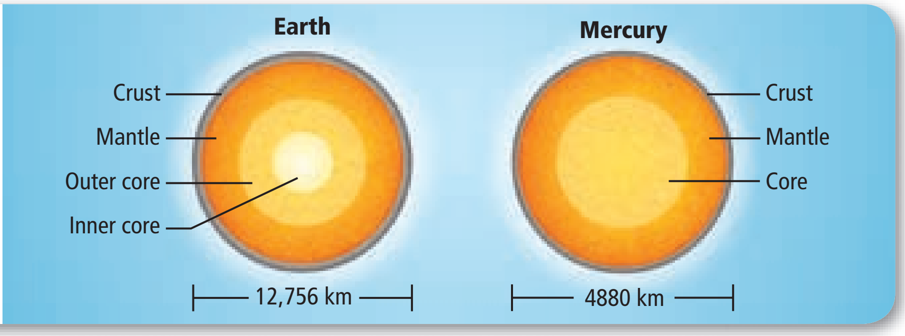
Reading Check **Compare** the surfaces of the Moon and Mercury.

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.



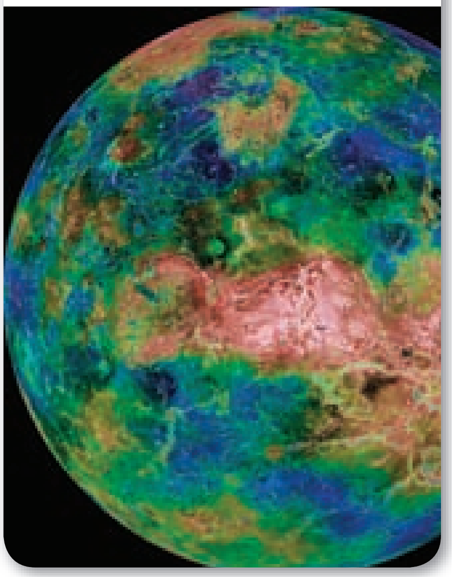
Early Mercury Mercury's small size, high density, and probable molten interior resemble what Earth might be like if its crust and mantle were removed, as shown in **Figure 28.13.** These observations suggest that Mercury was originally much larger, with a mantle and crust similar to Earth's, and that 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.

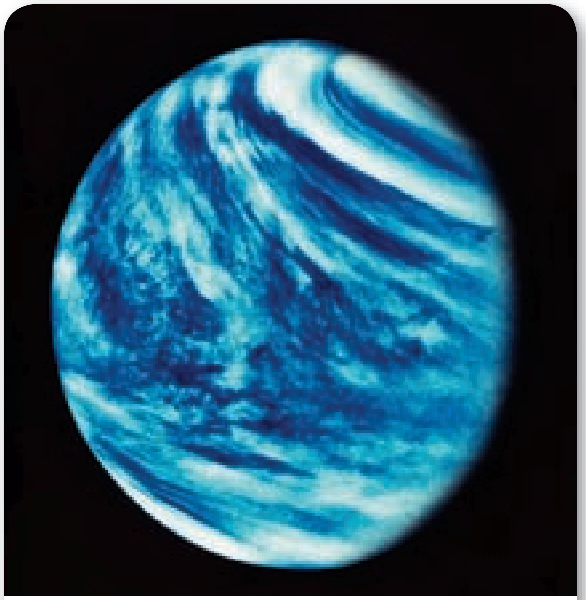
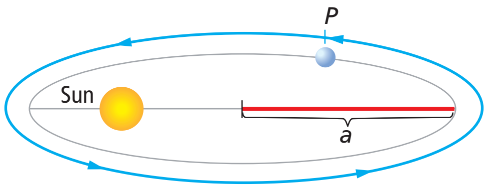


Figure 28.15 Clouds swirl around Venus in this image taken using ultraviolet wavelengths.

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.

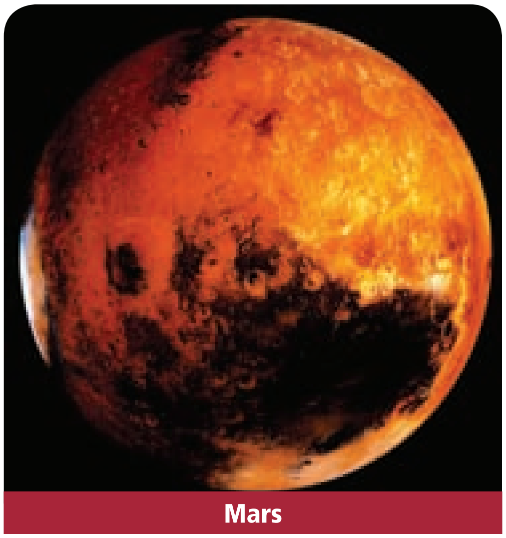
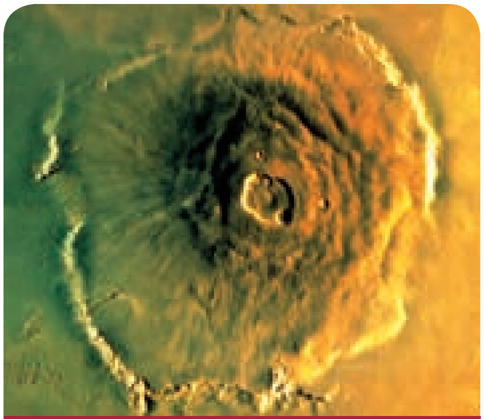
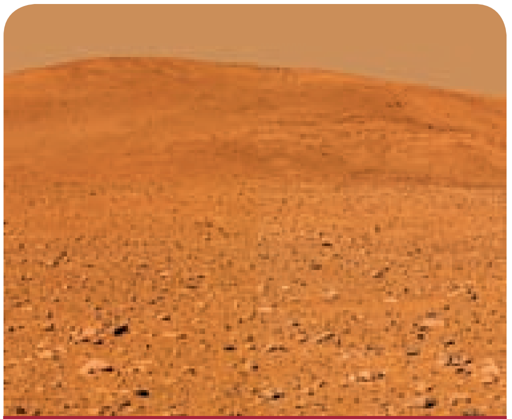


Figure 28.16 Earth's blue seas and white clouds contrast sharply with the reddish, barren Mars.



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.

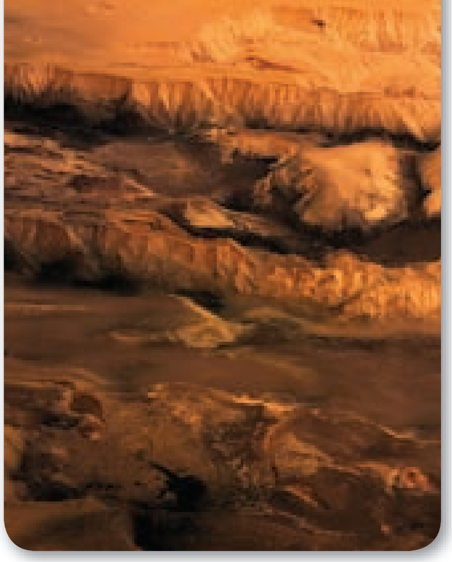
Atmosphere Both Mars and Venus have atmospheres of similar composition. The density and pressure of the atmosphere on Mars are much lower; therefore Mars does not have a strong greenhouse effect like Venus does. Although the atmosphere is thin, it is turbulent—there is constant wind, and dust storms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

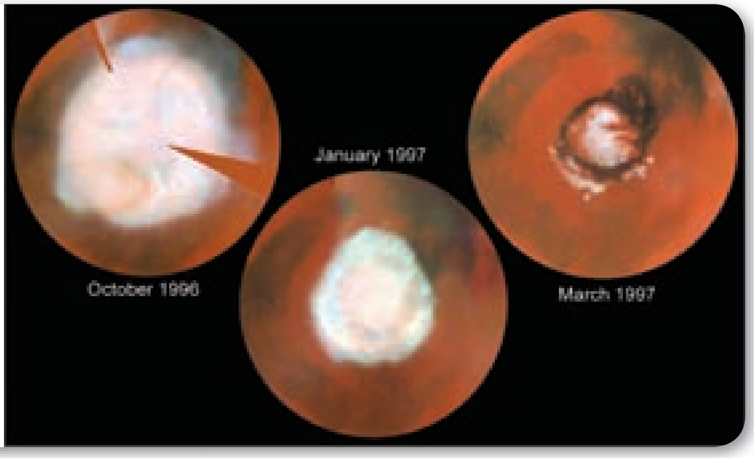
Tectonics An enormous canyon, Valles Marineris, shown in **Figure 28.18,** lies on the Martian equator, splitting the Tharsis Plateau. This canyon is 4000 km long—almost 10 times the length of the Grand Canyon on Earth and more than 3 times its depth. It probably formed as a fracture during a period 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?*



Phil James/Todd Clancy/Steve Lee/NASA

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

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 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.

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

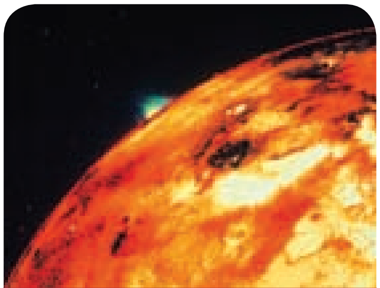
Jupiter's rings

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.

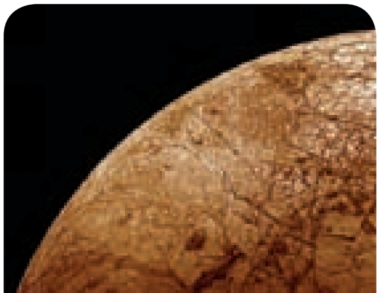
Rotation Jupiter rotates very rapidly for its size; it spins once on its axis in a little less than 10 hours, giving it the shortest day in the solar system. This rapid rotation distorts the shape of the planet so that the diameter through its equatorial plane is 7 percent larger than the diameter through 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.

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

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.

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.

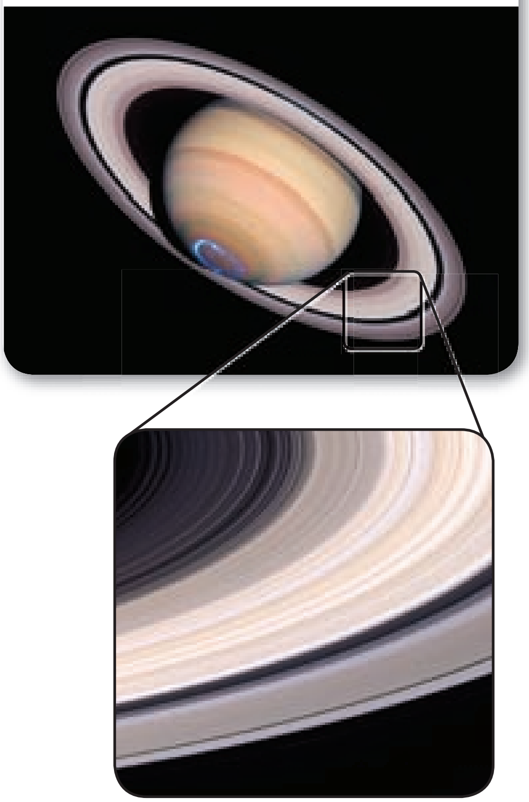
Rings Saturn's most striking feature is its rings, which are shown in **Figure 28.22.** Saturn's rings are much broader and brighter than those of the other gas giant planets. They are composed of pieces of ice that range from microscopic particles to house-sized chunks. There are seven major rings,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

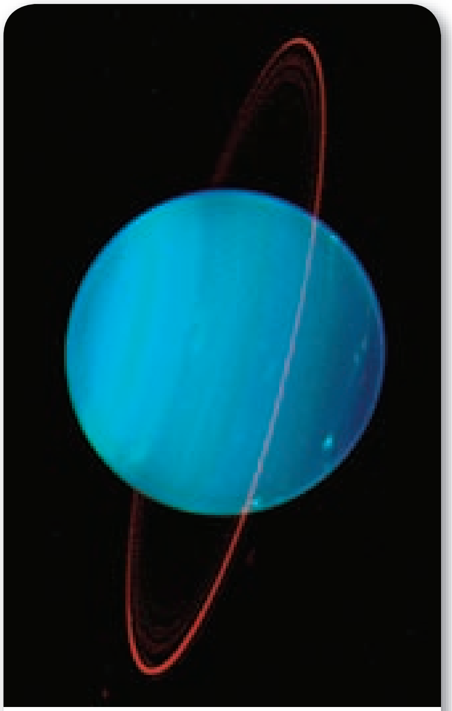
These ringlets and gaps are caused by the gravitational effects of Saturn's many moons. The rings are thin—less than 200 m thick—because rotational forces keep the orbits of all the particles confined to Saturn's equatorial plane. The ring particles have not combined to form a large satellite because 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

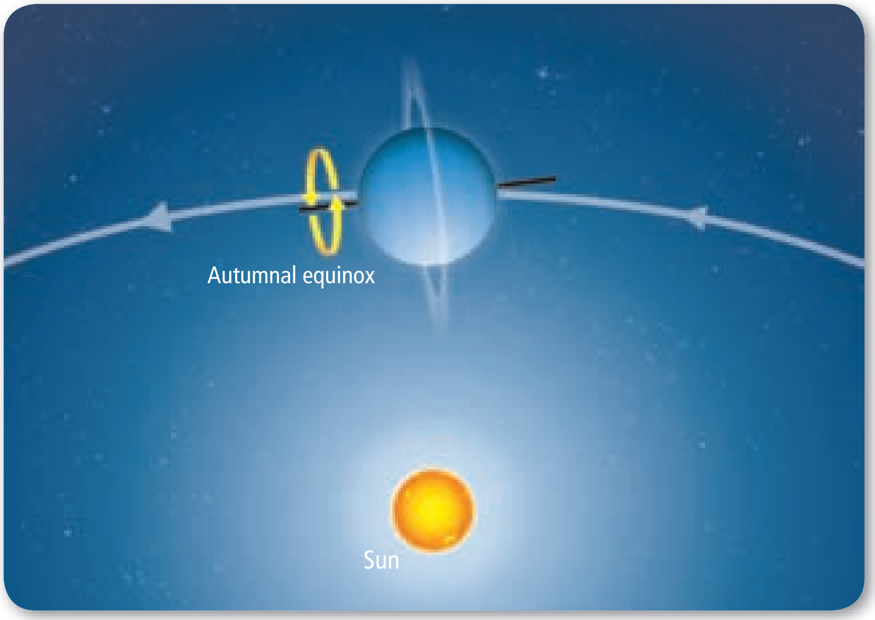
Uranus was discovered accidentally in 1781, when a bluish object was observed moving relative to the stars. In 1986, *Voyager 2* flew by Uranus and provided detailed information about the planet, including the existence of new moons and rings. Uranus's average temperature is 58 K (–215°C).

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.*

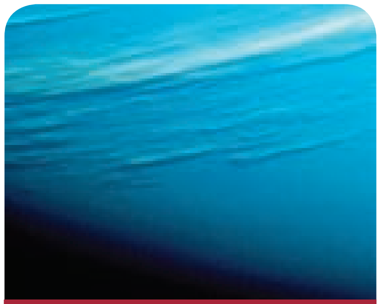


Neptune

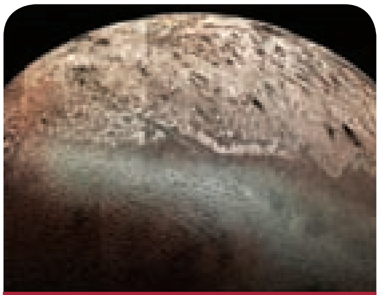
The existence of Neptune was predicted before it was discovered, based on small deviations in the motion of Uranus and the application of Newton's universal law of gravitation. In 1846, Neptune was discovered where astronomers had predicted it to be. Few details can be observed on Neptune with an Earth-based 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.

Objectives

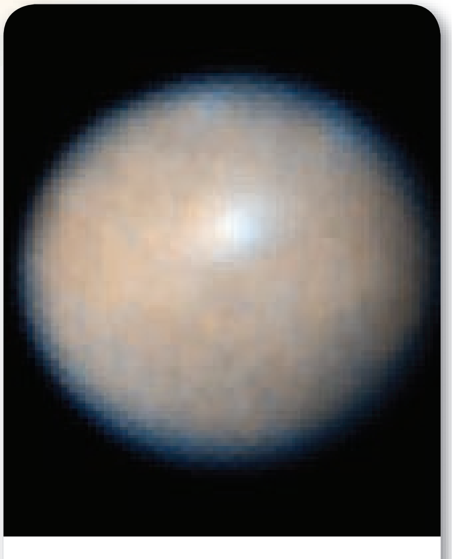
- **Distinguish** between planets and dwarf planets.
- **Identify** the oldest members of the solar system.
- **Describe** meteoroids, meteors, and meteorites.
- **Determine** the structure and behavior of comets.

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.

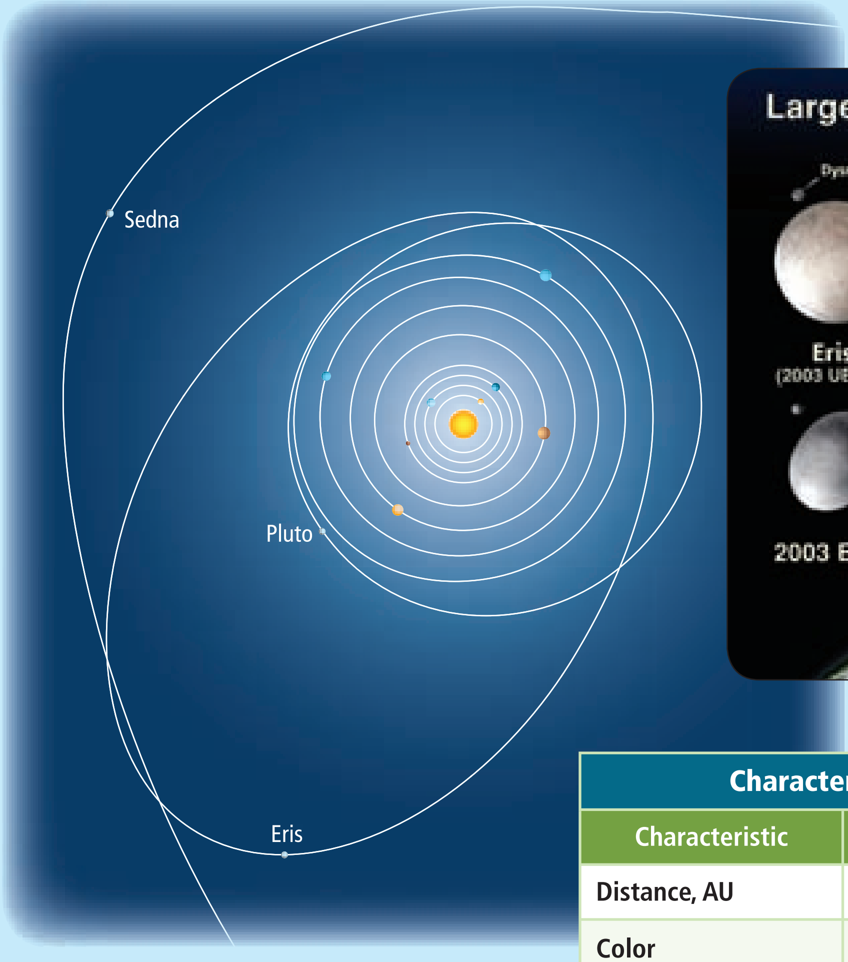
Ceres In 1801, Giuseppe Piazzi discovered a large object in orbit between Mars and Jupiter. Scientists had predicted that there was a planet somewhere in that region, and it seemed that this discovery was it. However, Ceres, shown in **Figure 28.26,** was extremely small for a planet. In the following 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

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

Small Solar System Bodies

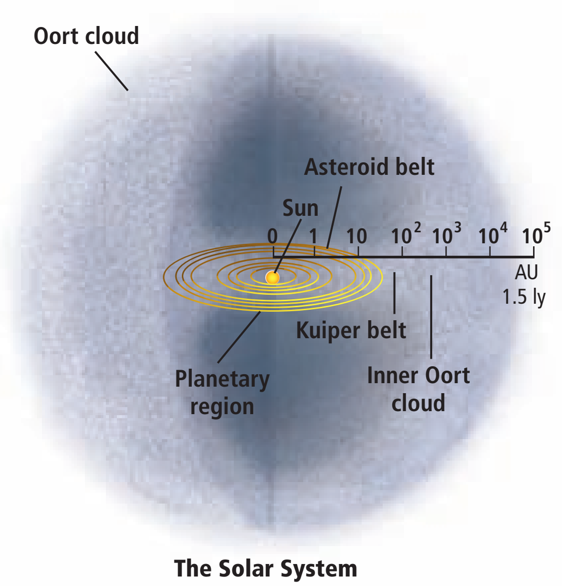
Once the IAU defined planets and dwarf planets, they had to identify what was left. In the early 1800s, a name was given to the rocky planetesimals between Mars and Jupiter—the asteroid belt. Objects beyond the orbit of Neptune have been called trans-Neptunian objects (TNOs), Kuiper belt objects (KBOs), 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.

■ **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.



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.**

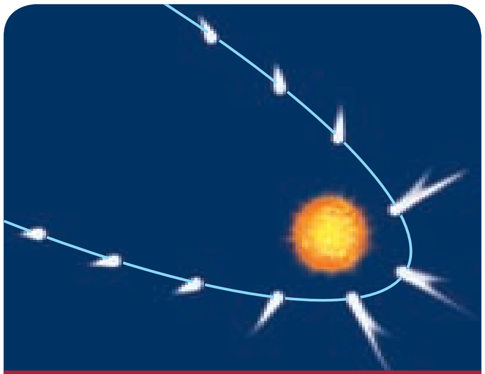
Dan Schechter/Photo Researchers

Comets

Comets are small, icy bodies that have highly eccentric orbits around the Sun. Ranging from 1 to 10 km in diameter, most comets orbit in a continuous distribution that extends from the Kuiper belt to 100,000 AU from the Sun. The outermost region is known as the Oort cloud and expands into a sphere surrounding the Sun. Occasionally, a comet is disturbed by the gravity of another object and is thrown into the inner solar system.

Comet structure When a comet comes within 3 AU of the Sun, it begins to evaporate. It forms a head and one or more tails. The head is surrounded by an envelope of glowing gas, and it has a small solid core. The tails form as gas and dust are pushed away from comet by particles and radiation from the Sun. This is why comets' tails always point away from the Sun, as shown in **Figure 28.30.**

Periodic comets Comets that repeatedly return to the inner solar system are known as periodic comets. One example is Halley's comet, which has a 76-year period—it appeared last in 1985, and is expected to appear again in 2061. Each time a periodic comet comes near the Sun, it loses some of its matter, leaving behind a trail of particles. When Earth crosses the trail of a comet, particles left in the trail burn in Earth's upper atmosphere producing bright streaks of light called a **meteor shower.** In fact, most meteors are caused by dust particles from comets.



Comet in Sun Orbit

Comet Hale-Bopp

Figure 28.30 A comet's tail always points away from the Sun and is driven by a stream of particles and radiation. The comet Hale-Bopp was imaged when its orbit brought it close to the Sun in 1997.

Section 28.4 Assessment

Section Summary

- Dwarf planets, asteroids, and comets formed from the debris of the solar system formation.
- Meteoroids are planetesimals that enter Earth's atmosphere.
- Mostly rock and ice, the Kuiper belt objects are currently being detected and analyzed.
- Periodic comets are in regular, permanent orbit around the Sun, while others might pass this way only once.
- The outermost regions of the solar system house the comets in what is known as the Oort cloud.

Understand Main Ideas

1. MAIN Idea **Identify** the kinds of small solar system bodies and their compositions.
2. **Compare** planets and dwarf planets.
3. **Distinguish** among meteors, meteoroids, and meteorites.
4. **Explain** why a comet's tail always points away from the Sun.
5. **Compare and contrast** the asteroid belt and the Kuiper belt.

Think Critically

6. **Infer** why comets have highly eccentric orbits.

WRITING in Earth Science

7. Suppose you are traveling from the outer reaches of the solar system toward the Sun. Write a scientifically accurate description of the things you see.

EARTH SCIENCE AND TECHNOLOGY

NASA/JPL/Space Science Institute

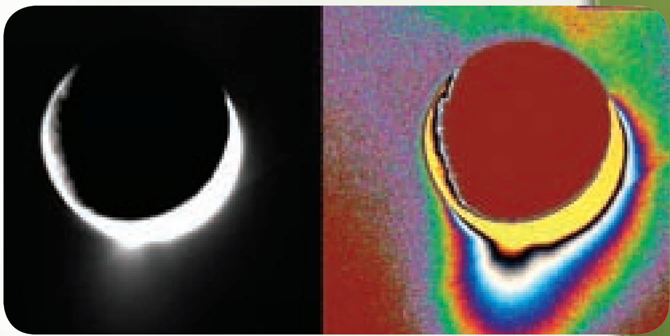
WATER IN THE SOLAR SYSTEM

In recent years, data collected by spacecraft have shown evidence of water in places in our solar system other than Earth. Scientists think there might be water, either in a liquid or solid state, on Earth's Moon, under the poles of Mercury and Mars, on several of Jupiter's moons, and on at least one of Saturn's moons. Further investigation and data collection is planned by NASA to confirm these findings.

Earth's Moon Several spacecraft have collected evidence that leads scientists to believe there is subsurface ice at the Moon's poles. In 1994 and 1998, spacecraft possibly detected ice and water. Scientists hope to find definitive evidence of water under the surface of the Moon with the *Lunar Reconnaissance Orbiter (LRO)*, set to launch in 2008. A probe will take samples to test for water.

Mercury's poles Because Mercury's axis is not tilted, the interior temperatures of large craters at the poles do not ever rise above –212°C. Radar images lead scientists to think that ice exists in these craters. In August 2004, NASA launched the *Messenger* spacecraft that will reach Mercury in 2011. *Messenger* is equipped with a spectrometer that will be used to detect hydrogen, which is part of water, at Mercury's poles.

Mars's north pole Using a spectrometer, the *Odyssey* spacecraft recorded high levels of hydrogen just beneath the surface at Mars's north pole in 2002. Scientists think that water exists there in the form of ice, and that the soil might be comparable to the permafrost found at high latitudes on Earth. The *Phoenix Lander,* scheduled to launch in 2007 and reach Mars in 2008, is equipped with a robotic arm that will drill into the surface of Mars at the pole. A specialized sensor will be able to detect if there is any water in the soil.



This colorized image shows the plume of liquid water ejected from Enceladus's surface in geyserlike eruptions.

Jupiter's moons Ganymede, Europa, and Callisto all have icy surfaces. However, based on readings of the magnetic fields and high-resolution photos taken by the spacecraft *Galileo* of all three moons, scientists hypothesize that they each have a subsurface ocean. NASA has proposed a new mission to Jupiter called *Jupiter Icy Moons Orbiter* (JIMO) that would launch in 2015 and orbit the three moons. The main goals of the mission would be to learn more about the history of the moons, map their surfaces, and confirm the existence of subsurface oceans.

Saturn's moon—Enceladus The spacecraft *Cassini* has recorded geyserlike eruptions of liquid water coming from the surface of Enceladus, even though the moon's average temperature is –201°C. The figure above shows a colorized image of such an eruption.

WRITING in Earth Science

Poster Research more information about where in the solar system water might exist. Make a poster that shows the bodies of the solar system and if water might be found on them. Include captions that explain what type of exploration is planned. To learn more about the water in the solar system, visit glencoe.com.

GEOLAB

DESIGN YOUR OWN: MODEL THE SOLAR SYSTEM

Background: Models are useful for understanding the scale of the solar system.

Question: *How can you choose a scale that will easily demonstrate relative sizes of objects and distances between them in the solar system?*

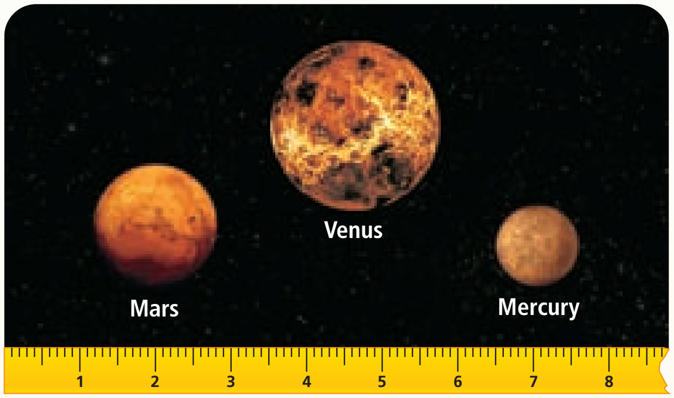
Materials

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

Safety Precautions

Procedure

1. Read and complete the lab safety form.
2. Develop a plan to make a model showing the relative sizes of objects in the solar system and the distances between them.
3. Make sure your teacher approves your plan before you begin.
4. Design a data table for the information needed to complete your model. Include the original data and the scale data.
5. Select a scale for your model using SI units. Remember your model should have the same scale throughout.
6. Calculate the relative sizes and distances of the objects you plan to model.
7. Select the materials and quantities of each, and build your model according to the scale you selected.



1 cm = 4000 km

Remember that the scale used has to include the largest and smallest objects and should be easy to produce.

Analyze and Conclude

1. **Think Critically** Why did the scale you chose work for your model?
2. **Explain** why you chose this scale.
3. **Observe and Infer** What possible problems could result from using a larger or smaller scale?
4. **Compare and Contrast** Compare your model with those of your classmates. Describe the advantages or disadvantages of your scale.

APPLY YOUR SKILL

Project Proxima Centauri, the closest star to the 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 modified your scale to better fit Proxima Centauri, how would this change the distance between Pluto and the Sun?

CHAPTER 28

Study Guide

STUDY TO GO — Download quizzes, key terms, and flash cards from glencoe.com.

BIG Idea Using the laws of motion and gravitation, astronomers can understand the orbits and the properties of the planets and other objects in the solar system.

Vocabulary	Key Concepts
Section 28.1 Formation of the Solar System	
• astronomical unit (p. 800) • eccentricity (p. 801) • ellipse (p. 800) • planetesimal (p. 798) • retrograde motion (p. 799)	**MAIN Idea** The solar system formed from the collapse of an interstellar cloud. • A collapsed interstellar cloud formed the Sun and planets from a rotating disk. • The inner planets formed closer to the Sun than the outer planets, leaving debris to produce asteroids and comets. • Copernicus created the heliocentric model and Kepler defined its shape and mechanics. • Newton explained the forces governing the solar system bodies and provided proof for Kepler's laws. • Present-day astronomers divide the solar system into three zones.
Section 28.2 The Inner Planets	
• scarp (p. 805) • terrestrial planet (p. 804)	**MAIN Idea** Mercury, Venus, Earth, and Mars have high densities and rocky surfaces. • 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.
Section 28.3 The Outer Planets	
• belt (p. 812) • gas giant planet (p. 811) • liquid metallic hydrogen (p. 812) • zone (p. 812)	**MAIN Idea** Jupiter, Saturn, Uranus, and Neptune have large masses, low densities, and many moons and rings. • 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.
Section 28.4 Other Solar System Objects	
• comet (p. 819) • dwarf planet (p. 816) • Kuiper belt (p. 818) • meteor (p. 818) • meteorite (p. 818) • meteoroid (p. 818) • meteor shower (p. 819)	**MAIN Idea** Rocks, dust, and ice compose the remaining 2 percent of the solar system. • Dwarf planets, asteroids, and comets formed from the debris of the sola system formation. • Meteoroids are planetesimals that enter Earth's atmosphere. • Mostly rock and ice, the Kuiper belt objects are currently being detected and analyzed. • Periodic comets are in regular, permanent orbit around the Sun, while others might pass this way only once. • The outermost regions of the solar system house the comets in the Oort cloud.

CHAPTER 28

Assessment

Vocabulary Review

Each of the following sentences is false. Make each sentence true by replacing the italicized words with terms from the Study Guide.

1. Rapid shrinkage of Mercury's crust, produced features on its surface called *rilles*.

2. The pattern of light and dark bands on Jupiter's surface are called belts and *flows*.

3. A *meteor* is a rocky object that strikes Earth's surface, forming a crater.

4. A *meteorite* formed as particles of dust and gas stuck together in the early solar system.

5. The apparent backward movement of Mars as Earth passes it in its orbit is *synchronous rotation.*

6. A *light-year* is a unit of measurement used to measure distances within the solar system.

Match each phrase below with the correct term from the Study Guide.

7. a small icy object having a highly eccentric orbit around the Sun

8. Mercury, Venus, Earth, and Mars

9. multiple streaks of light caused by dust particles burning in Earth's atmosphere

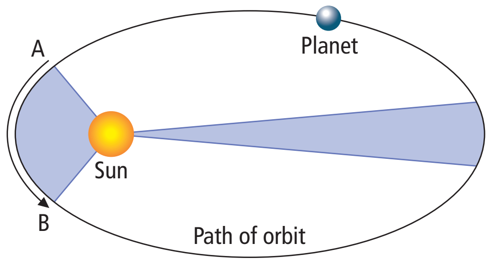
10. a measure of orbital shape

11. a new solar system body classification

Understand Key Concepts

12. Who first proposed the heliocentric model of the solar system?
A. Copernicus
B. Galileo
C. Kepler
D. Newton

Use the diagram below to answer Question 13.

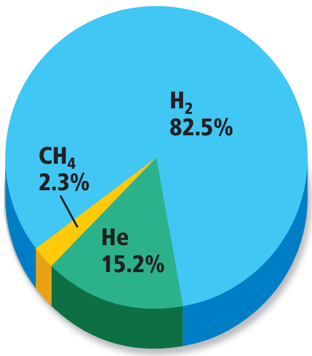


13. Which law of planetary motion does this diagram demonstrate?
A. Kepler's first law
B. Kepler's second law
C Kepler's third law
D. Newton's law of universal gravitation

14. Which best describes a planet's retrograde motion?
A. apparent motion
B. orbital motion
C. real motion
D. rotational motion

15. Which scientist determined each planet orbits a point between it and the Sun, called the center of mass?
A. Copernicus
B. Galileo
C. Kepler
D. Newton

Use the diagram below to answer Question 16.

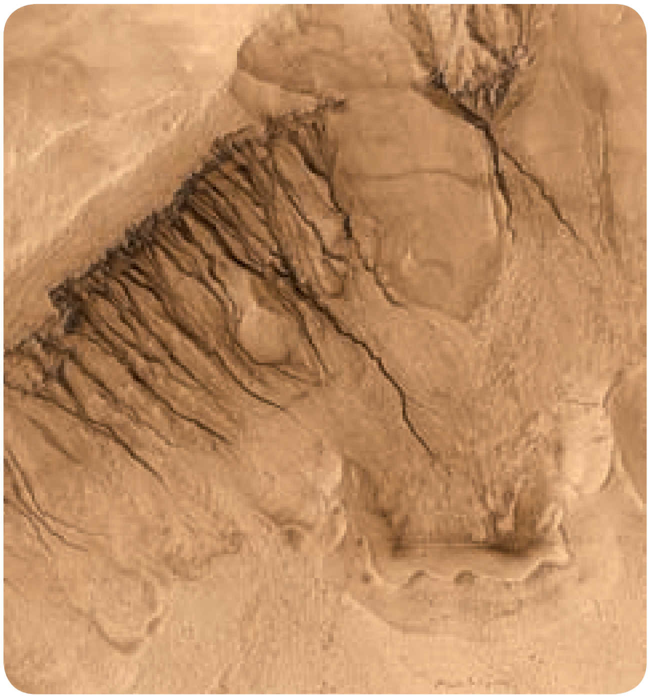


16. The atmospheric composition of which planet is shown above?
A. Jupiter
B. Mars
C. Neptune
D. Venus

17. Where do most meteorites originate?
    A. asteroid belt
    B. Kuiper belt
    C. Oort cloud
    D. Saturn's rings

Constructed Response

Use the photo below to answer Questions 18 and 19.



18. Identify these features shown on the surface of Mars and explain what most likely caused them.

19. Infer Based on what you have learned about Mars, state whether new features like these could be made now. Explain.

20. Compare Pluto and Eris and determine their common features.

21. Compare Sedna and EL61 to the dwarf planets and determine which features are common to each.

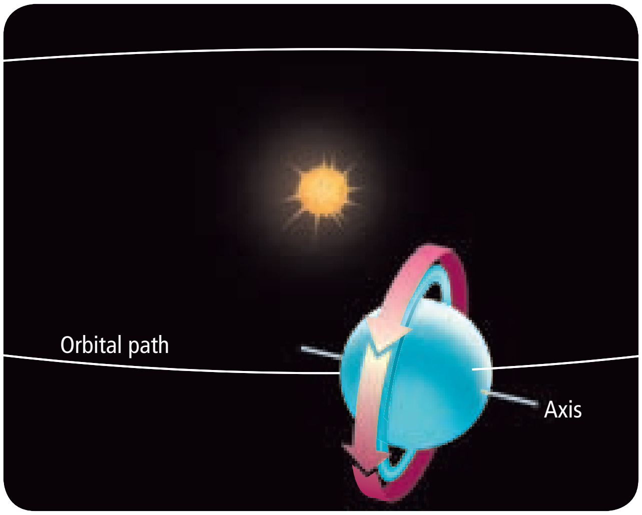
22. Explain why probes do not survive on the surface of Venus.

23. Compare the pivot point on a seesaw and a center of mass between two orbiting bodies.

24. Calculate Find the shape of an ellipse having an eccentricity of 0.9.

Use the diagram below to answer Questions 25 and 26.

JPL/NASA



25. Identify the planet shown here and explain why scientists think its rotational axis is like this.

26. Infer how the seasons would be affected if Earth had an axis tilt similar to Uranus.

Think Critically

27. Explain The atmospheres of Mars and Venus contain similar percentages of CO_2, but Venus has a much higher surface temperature because of the greenhouse effect. Why doesn't this happen on Mars?

28. CAREERS IN EARTH SCIENCE Most astronomers do not spend long hours peering through telescopes. They operate telescopes remotely using computers and spend most of their time analyzing data. What subjects would astronomers find most useful in addition to astronomy?

29. Discuss the theory of formation of the rings of Saturn and the other gas giant planets.

30. Infer the role gravity plays in the formation of the rings of the gas giant planets.

31. Infer what might happen to Halley's comet as it continues to lose mass with each orbit of the Sun.

32. Explain why scientists think Jupiter's moon Europa might have liquid water beneath its surface.

Earth Science Online Chapter Test glencoe.com

Use the table below to answer Questions 33 to 35.

Planet	Radius (km)	Orbital Eccentricity	Semimajor Axis (AU)
Mercury	2439.7	0.2056	0.39
Venus	6051.8	0.0067	0.72
Earth	6378.1	0.0167	1.00
Mars	3397	0.0935	1.52
Jupiter	71,492	0.0489	5.20
Saturn	60,298	0.0565	9.54
Uranus	25,559	0.047	19.19
Neptune	24,766	0.009	30.07

33. Interpret Which of the planets has an orbit that most closely resembles a perfect circle?

34. Compare Which two planets have the most similar radii?

35. Evaluate Which two planets' orbits are separated by the greatest distance?

36. Discuss the relationship between asteroids and planetesimals.

37. Explain Why were Ceres and Pluto identified as the first dwarf planets?

38. Compare and contrast the asteroid belt and the Kuiper belt.

Concept Mapping

39. Create a concept map using the following terms: *interstellar cloud, gas, dust, disk, particles, planetesimals, terrestrial planets, gas giant planets, satellites, debris, asteroids, meteoroids,* and *comets.*

Challenge Question

40. Consider Pluto's orbit sometimes brings it within the orbit of Neptune. Why is it unlikely that the two will collide? Explain.

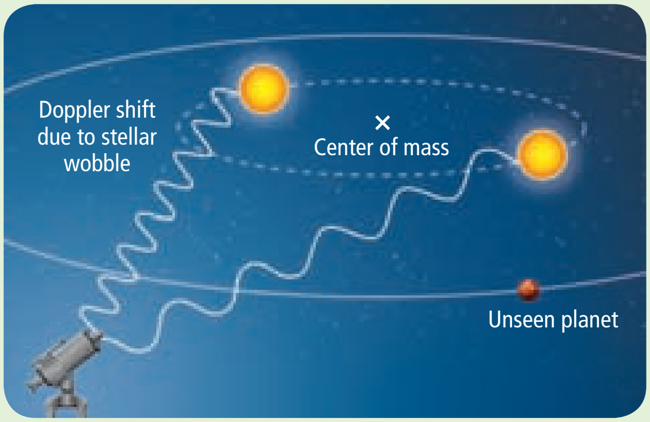
Additional Assessment

41. WRITING in **Earth Science** Write a paragraph to explain to a friend how science develops over time. Discuss the relationship between Kepler's laws and Newton's law of universal gravitation.

DBQ Document–Based Questions

Data obtained from: *Physics World*. 2001. (January): 25.

Astronomers have detected planets around more than 200 stars. Although the planets themselves are too small to see directly, astronomers can detect them by measuring the Doppler shift in the star's light as it orbits its common center of mass with the unseen planet. The diagram below shows how this works.



42. Based on the diagram, what is the rotational direction of the star? Explain.

43. Based on what you know about the center of mass, which planet in our solar system would be most likely to be detectable from other star systems using this method?

Cumulative Review

44. Name an example of a felsic, igneous rock. **(Chapter 5)**

45. Describe the relationship between ejecta and rays on the Moon's surface. **(Chapter 27)**

Standardized Test Practice

Multiple Choice

1. When foxes reach the brink of extinction in an area, what happens to the population of rabbits in the area?
   A. The rabbit population also becomes extinct.
   B. The rabbit population increases indefinitely.
   C. The rabbit population increases beyond the carrying capacity of the area, then decreases.
   D. The rabbit population decreases beyond the carrying capacity of the area, and then quickly increases.

Use the diagram below to answer Questions 2 and 3.

2. What results on Earth when the Sun and the Moon are aligned along the same direction?
   A. spring tides
   B. neap tides
   C. the autumnal equinox
   D. the summer solstice

3. If the Moon in this diagram were passing directly between the Sun and Earth, blocking the view of the Sun, what would you experience on Earth?
   A. a lunar eclipse
   B. a solar eclipse
   C. umbra
   D. penumbra

4. Earth's main energy source is
   A. fossil fuels
   B. hydrocarbons
   C. the Sun
   D. wind

5. Which describes life during the early Proterozoic Era?
   A. simple, unicellular life forms
   B. complex, unicellular life forms
   C. simple, multicellular life forms
   D. complex, multicellular life forms

6. Which is not considered a biomass fuel?
   A. peat
   B. coal
   C. fecal material
   D. wood

Use the illustration below to answer Questions 7 and 8.

7. Which type of fossil preservation is shown?
   A. trace fossil
   B. original remains
   C. carbon film
   D. permineralized remains

8. By studying the fossils, which is not something scientists can learn about the organism that left these prints?
   A. movement
   B. size
   C. habitat
   D. walking characteristics

9. When minerals in rocks fill a space left by a decayed organism, what type of fossils is formed?
   A. trace fossil
   B. cast fossil
   C. petrified fossil
   D. amber-preserved fossil

10. How are Mercury and the Moon similar?
    A. Both are covered with craters and plains.
    B. Both have the same night-to-day temperature difference.
    C. They have the same strength of surface gravity.
    D. Both have an extensive nickel-iron core.

Short Answer

Use the table below to answer Questions 11 to 13.

Apparent Temperature Index					
		Relative Humidity (%)			
Air Tempearture (F°)		80	85	90	95
	85	97	99	102	105
	80	86	87	88	89
	75	78	78	79	79
	70	71	71	71	71

11. If the air temperature is 24°C and the relative humidity is 85%, what would the apparent temperature feel like?

12. What can be inferred about the effect relative humidity has on apparent temperature as the air temperature increases?

13. In the fall, when temperatures are moderate, how should a person plan for temperature with relative humidity factored in?

14. Although a hybrid car still requires fuel to run, why is it considered a good energy resource?

15. What are some steps mining companies are taking to be less destructive to the environment?

Reading for Comprehension

Tau Gruis, The Newest Planet

An international team of researchers has discovered the 100th "extrasolar" planet. This newest planet orbits the star Tau Gruis, 100 light-years from Earth, in the southern hemisphere's constellation Grus (the crane). In order to actually detect a planet, a planet must be seen going around its orbit at least once. Although scientists have been watching Tau Gruis since 1998, this is the first time that they have been able to confirm the presence of its large planet. This is an indication that there is a considerable distance between the star and the planet. Soon after the first extrasolar planets were found, beginning in 1995, most planets were found in orbit close to their host stars. Planets closer to their suns orbit at a much faster rate, and therefore take much less time to detect. Starting out, planets close in to their parent stars were found. But as the planet search program has matured, more planets farther out and in nearly circular orbits are being found. This means that scientists are getting closer to detecting more systems that are similar to our own solar system.

Article obtained from: Brendle, A. Hundredth planet outside solar system discovered. *National Geographic News.* September 17, 2002.

16. What can be inferred from this passage?
A. Our solar system is unique.
B. Detecting planets is virtually impossible.
C. As technology improves, more planets will be found.
D. Large planets are harder to find than small planets.

17. What must happen in order for an object to be considered a planet?
A. The object must go around its orbit at least once.
B. It must orbit its parent star at a particular speed.
C. It must be a particular size.
D. It must be within 100 light-years of Earth.

NEED EXTRA HELP?															
If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Review Section . . .	26.1	27.3	27.3	25.1	22.4	25.1	21.4	21.4	21.4	28.2	11.2	11.2	11.2	25.3	26.2