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

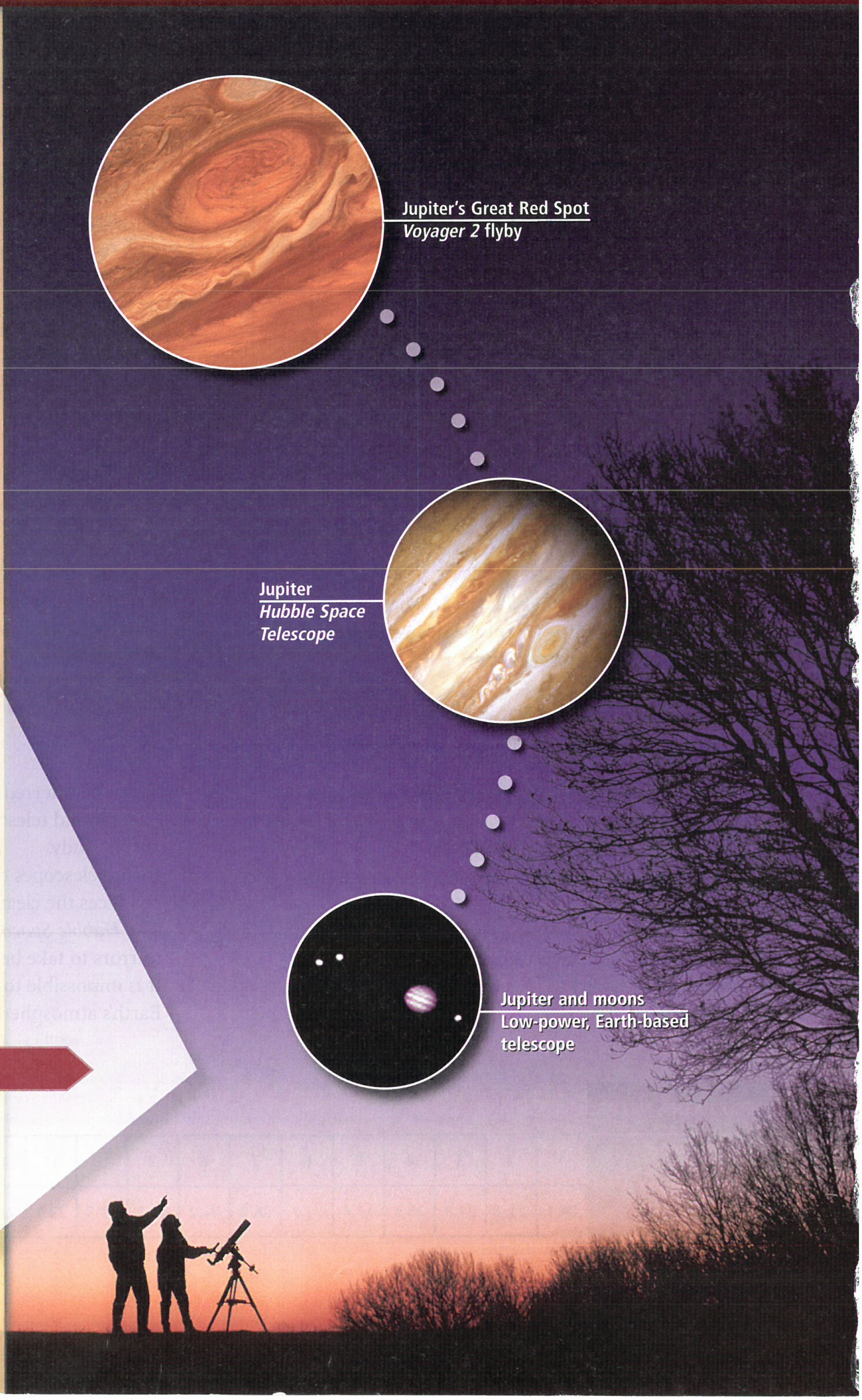
MAIN Idea Mercury, Venus, Earth, and Mars have high densities and rocky surfaces.

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.

Start-Up Activities

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

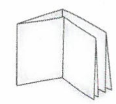
1. **Summarize** in a table what scientists learned from each mission or what they hope to learn.
2. **Determine** which missions are still in progress, which ones have gone beyond their mission life, and which ones have been completed.
3. **Suggest** other missions that could be conducted in the future.

FOLDABLES™ Study Organizer

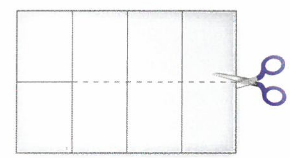
The Planets Make the following Foldable that features the planets of our solar system.

STEP 1 Fold a sheet of paper in half.

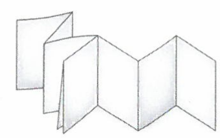
STEP 2 Fold in half and then in half again to form eight sections.



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

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

Formation of the Solar System

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 (kg/m^3)	Atmosphere	Distance from the Sun (AU)	Moons
Mercury	4,880	0.06	5430	none	0.39	0
Venus	12,104	0.821	5240	CO_2, N_2	0.72	0
Earth	12,742	1.00	5520	N_2, O_2, H_2O	1.00	1
Mars	6,778	0.21	3930	CO_2, N_2, Ar	1.52	2
Jupiter	139,822	317.8	1330	H_2, He	5.2	63
Saturn	116,464	95.2	700	H_2, He	9.58	47
Uranus	50,724	14.5	1300	H_2, He, CH_4	19.2	27
Neptune	49,248	17.1	1760	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. Some of their properties are given in **Table 28.1.**

FOLDABLES
Incorporate information from this section into your Foldable.

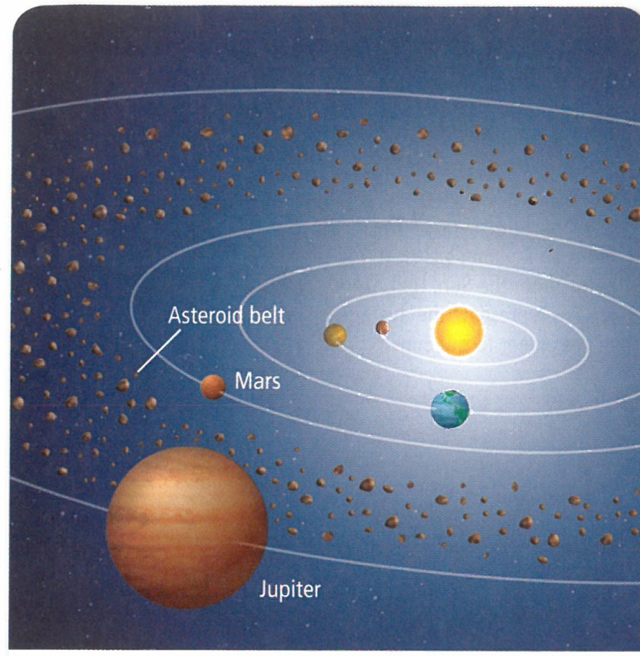
Gas giants form The first large planet to develop was Jupiter. Jupiter increased in size through the merging of icy planetesimals that contained mostly lighter elements. It grew larger as its gravity attracted additional gas, dust, and planetesimals. Saturn and the other gas giants formed similarly, 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.

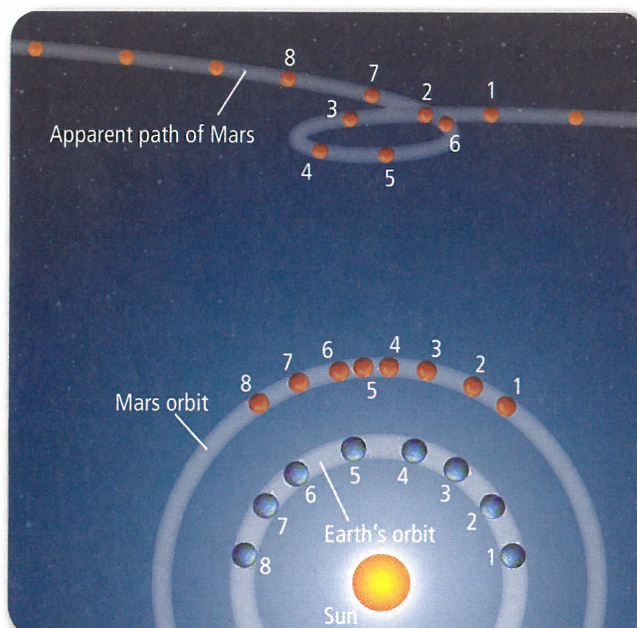
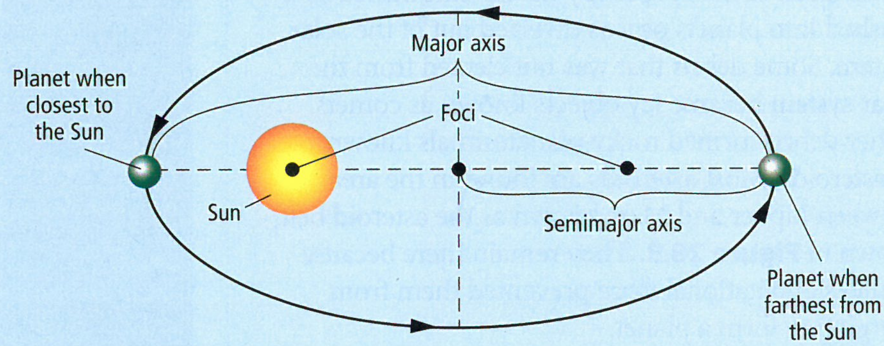


Figure 28.5 This diagram shows the geometry of an ellipse using an exaggerated planetary orbit. The Sun lies at one of the two foci. The minor axis of the ellipse is its shorter diameter. The major axis of the ellipse is its longer diameter, which equals the distance between a planet's closest and farthest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

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). Distance in space is often measured in Au. For example, Mars is 1.52 Au from the Sun.

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

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.

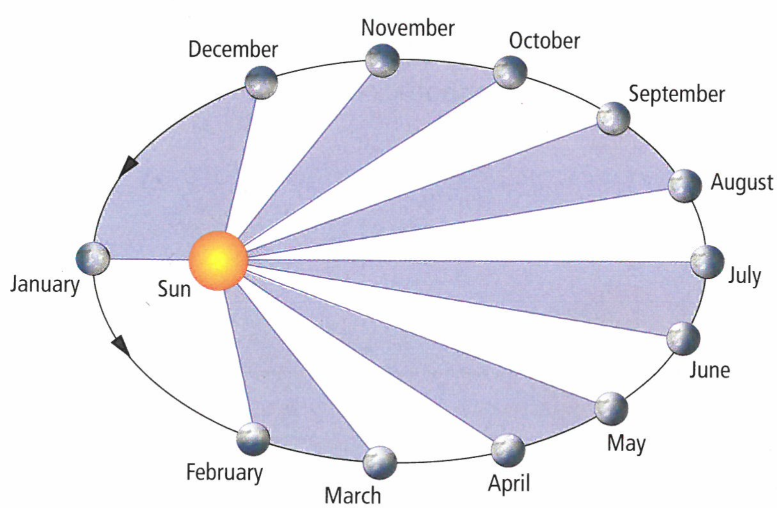
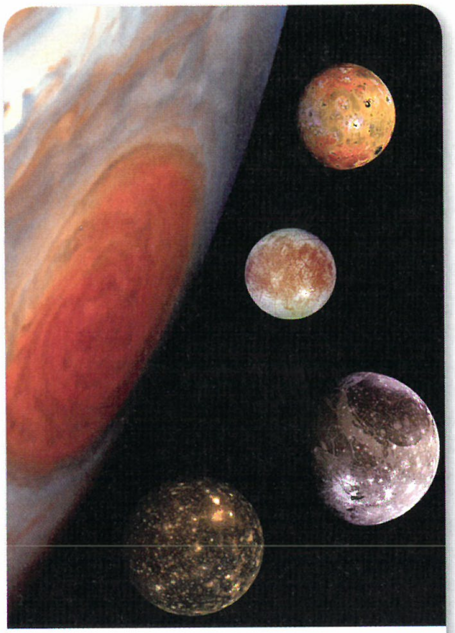


Figure 28.6 Kepler's second law states that planets move faster when close to the Sun and slower when farther away. This means that a planet sweeps out equal areas in equal amounts of time. (Note: *not drawn to scale*)



■ **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.

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.

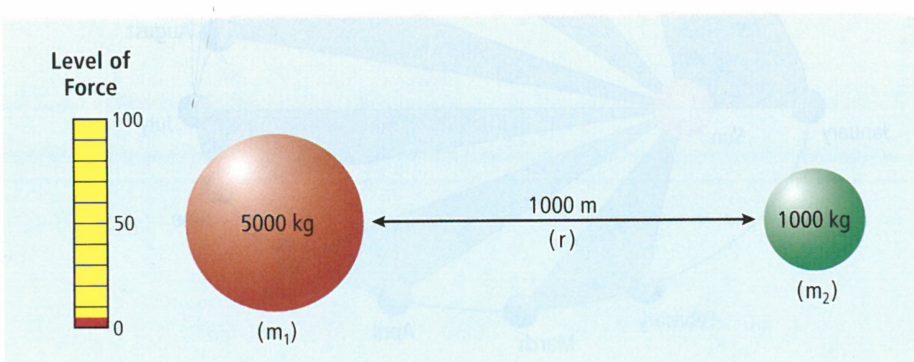
Gravity and orbits Newton realized that this attractive force could explain why planets move according to Kepler's laws. He observed the Moon's motion and realized that its direction changes because of the gravitational attraction of Earth. In a sense, the Moon is constantly falling toward Earth. If 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 3.3×10^{-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.

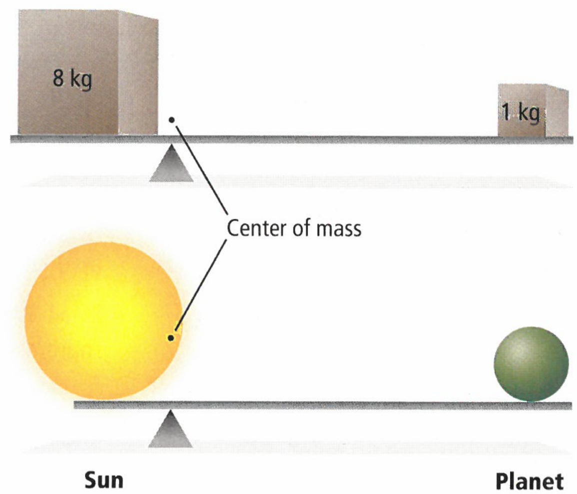


Figure 28.9 Just as the balance point on a seesaw is closer to the heavier box, the center of mass between two orbiting bodies is closer to the more massive body.

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.

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.