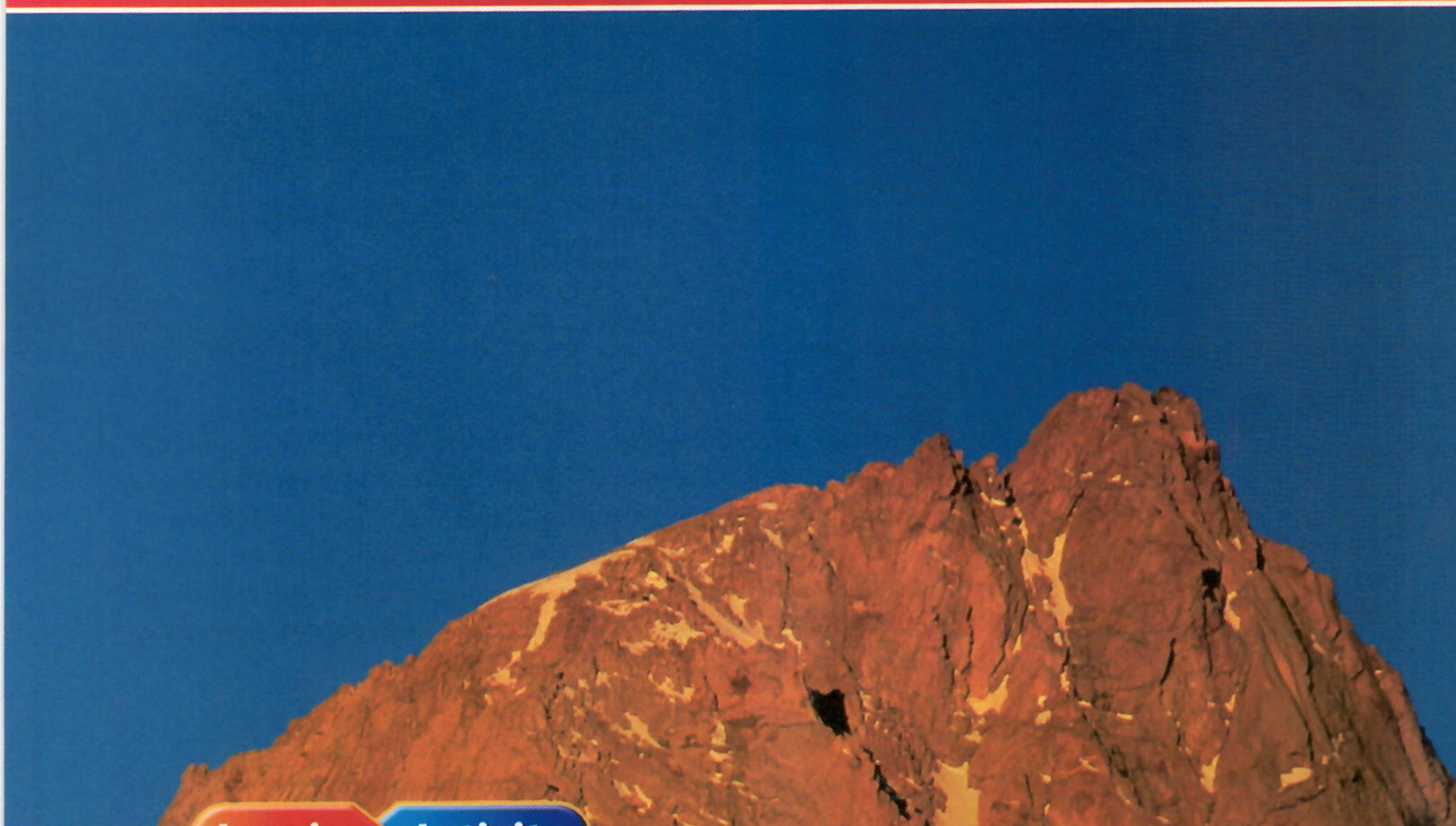
Chapter Preview



Inquiry Activity

How Do Impact Craters Form?

Procedure

1. Fill a large, plastic container with sand to a depth of about 3 cm. Flatten the surface of the sand with a wooden ruler.
2. One at a time, drop each of the different-sized balls from heights of 0.5 m, 1 m, and 2 m into the container. Make sure to smooth the surface of the sand between each drop.
3. Measure the diameter and height of the crater produced each time. Record your measurements in a data table.

Think About It

1. **Making Graphs** Identify your dependent and independent variables. Then plot your data on a line graph.
2. **Controlling Variables** Which of the variables is directly related to the velocity of the falling objects?
3. **Drawing Conclusions** Examine your data closely. What can you conclude about the general relationships between crater size and the size, mass, and velocity of the object that produced the crater?

22.1 Early Astronomy

Reading Focus

Key Concepts

- How does the geocentric model of the solar system differ from the heliocentric model?
- What were the accomplishments of early astronomers?

Vocabulary

- astronomy
- geocentric
- heliocentric
- retrograde motion
- ellipse
- astronomical unit (AU)

Reading Strategy

Comparing and Contrasting Copy the table below. As you read about the geocentric and heliocentric models of the solar system, fill in the table.

	Location of Earth	Location of Sun	Supporters of Model
Geocentric Model	center of universe	a. ?	b. ?
Heliocentric Model	c. ?	d. ?	e. ?

Earth is one of nine planets and many smaller bodies that orbit the sun. The sun is part of a much larger family of perhaps 100 billion stars that make up our galaxy, the Milky Way. There are billions of galaxies in the universe. A few hundred years ago scientists thought that Earth was the center of the universe. In this chapter, you will explore some events that changed the view of Earth's place in space. You will also examine Earth's moon.

Figure 1 Early astronomers often used instruments called astrolabes to track the positions of the sun and stars.

Ancient Greeks

Astronomy is the science that studies the universe. Astronomy deals with the properties of objects in space and the laws under which the universe operates. The "Golden Age" of early astronomy (600 B.C.–A.D. 150) was centered in Greece. The early Greeks used philosophical arguments to explain natural events. However, they also relied on observations. The Greeks used instruments such as the one in Figure 1. The Greeks developed the basics of geometry and trigonometry. Using these branches of mathematics, they measured the sizes and distances of the sun and the moon.

The Greeks made many astronomical discoveries. The famous Greek philosopher Aristotle (384–322 B.C.) concluded that Earth is round because it always casts a curved shadow on the moon when it passes between the sun and the moon. Aristotle's belief that Earth is round was largely abandoned in the Middle Ages.

The first successful attempt to establish the size of Earth is credited to Eratosthenes (276–194 B.C.). As shown in Figure 2, Eratosthenes observed the angles of the noonday sun in two Egyptian cities that were roughly north and south of each other—Syene (presently Aswan) and Alexandria. Finding that the angles differed by 7 degrees, or 1/50 of a complete circle, he concluded that the circumference of Earth must be 50 times the distance between these two cities. The cities were 5000 stadia apart, giving him a measurement of 250,000 stadia. Many historians believe the stadia was 157.6 meters. This would make Eratosthenes' calculation of Earth's circumference—39,400 kilometers—a measurement very close to the modern circumference of 40,075 kilometers.

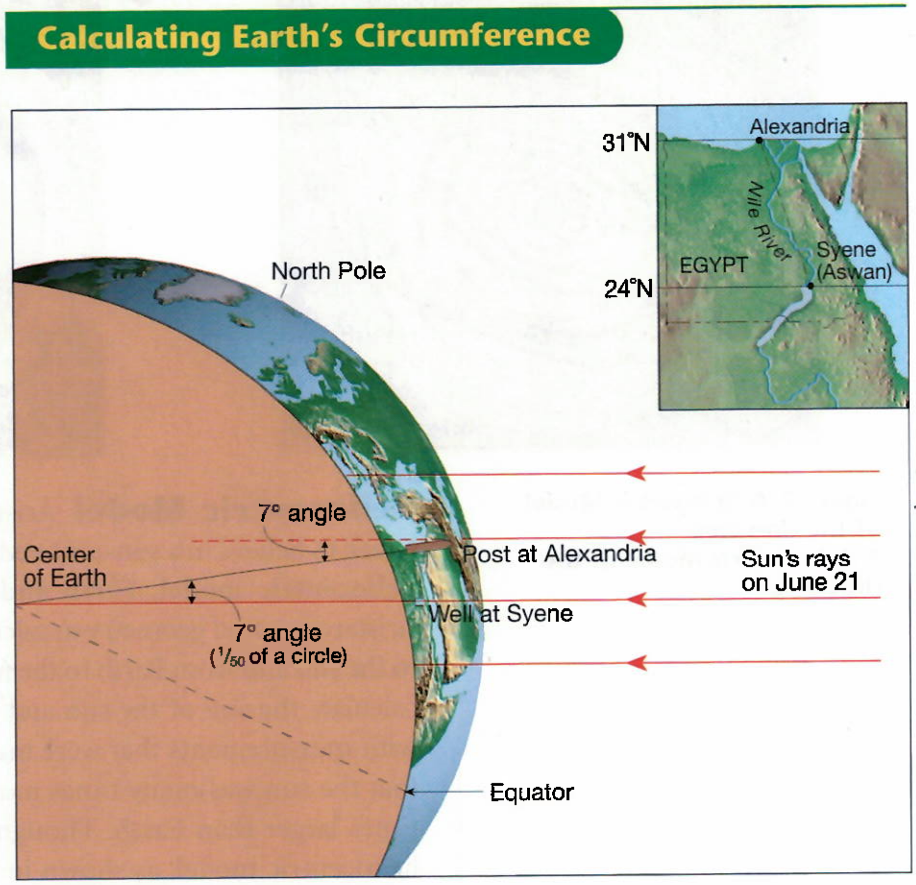


Figure 2 This diagram shows the orientation of the sun's rays at Syene (Aswan) and Alexandria in Egypt on June 21 when Eratosthenes calculated Earth's circumference.

Probably the greatest of the early Greek astronomers was Hipparchus (second century B.C.), best known for his star catalog. Hipparchus determined the location of almost 850 stars, which he divided into six groups according to their brightness. He measured the length of the year to within minutes of the modern year and developed a method for predicting the times of lunar eclipses to within a few hours.

Geocentric Model The Greeks believed in the **geocentric** view. They thought that Earth was a sphere that stayed motionless at the center of the universe. **In the geocentric model, the moon, sun, and the known planets—Mercury, Venus, Mars, and Jupiter—orbit Earth.** Beyond the planets was a transparent, hollow sphere on which the stars traveled daily around Earth. This was called the celestial sphere. To the Greeks, all of the heavenly bodies, except seven, appeared to remain in the same relative position to one another. These seven wanderers included the sun, the moon, Mercury, Venus, Mars, Jupiter, and Saturn. Each was thought to have a circular orbit around Earth. The Greeks were able to explain the apparent movements of all celestial bodies in space by using this model. This model, however, was not correct. Figure 3A on page 616 illustrates the geocentric model.

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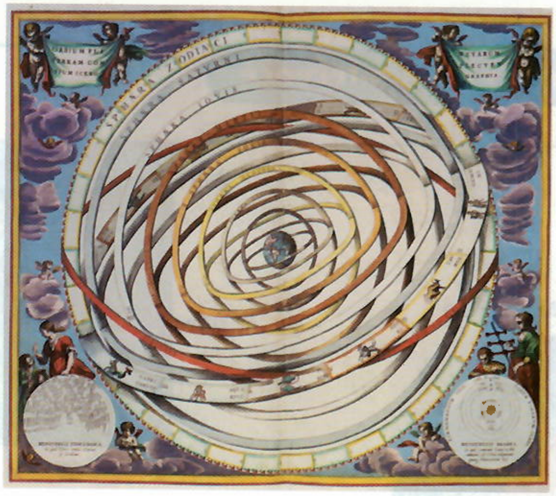


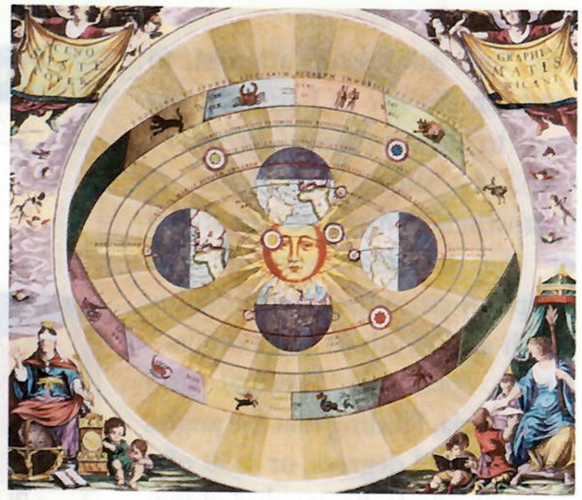


Figure 3 A Geocentric Model of the Universe
B Heliocentric Model of the Universe

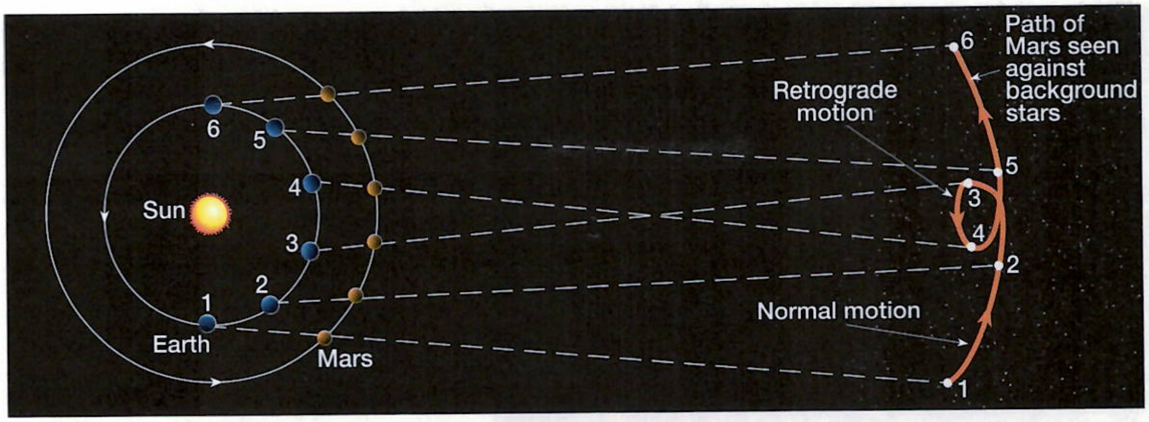
Heliocentric Model Aristarchus (312–230 B.C.) was the first Greek to believe in a sun-centered, or **heliocentric,** universe. **In the heliocentric model, Earth and the other planets orbit the sun.** Aristarchus used geometry to calculate the relative distances from Earth to the sun and from Earth to the moon. He later used these distances to calculate the size of the sun and the moon. But Aristarchus came up with measurements that were much too small. However, he did learn that the sun was many times more distant than the moon and many times larger than Earth. Though there was evidence to support the heliocentric model, as shown in Figure 3B, the Earth-centered view, shown in Figure 3A, dominated Western thought for nearly 2000 years.

Ptolemaic System Much of our knowledge of Greek astronomy comes from Claudius Ptolemy. In a 13-volume work published in A.D. 141, Ptolemy presented a model of the universe that was called the Ptolemaic system. It accounted for the movements of the planets. The precision with which his model was able to predict the motion of the planets allowed it to go unchallenged for nearly 13 centuries.

Just like the Greeks, Ptolemy's model had the planets moving in circular orbits around a motionless Earth. However, the motion of the planets against the background of stars seemed odd. Each planet, if watched night after night, moves slightly eastward among the stars. Periodically, each planet appears to stop, reverse direction for a time, and then resume an eastward motion. The apparent westward drift is called **retrograde motion** and is diagrammed in Figure 4 on page 617. This rather odd apparent motion results from the combination of the motion of Earth and the planet's own motion around the sun, as shown in Figure 4.

It is difficult to accurately represent retrograde motion by using the Earth-centered model. Even though Ptolemy used the wrong model, he was able to account for the planets' motions.

Reading Checkpoint *What is retrograde motion?*



The Birth of Modern Astronomy

The development of modern astronomy involved a break from previous philosophical and religious views. Scientists began to discover a universe governed by natural laws. We will examine the work of five noted scientists: Nicolaus Copernicus, Tycho Brahe, Johannes Kepler, Galileo Galilei, and Sir Isaac Newton.

Nicolaus Copernicus For almost 13 centuries after the time of Ptolemy, very few astronomical advances were made in Europe. The first great astronomer to emerge after the Middle Ages was Nicolaus Copernicus (1473–1543) from Poland. Copernicus became convinced that Earth is a planet, just like the other five planets that were known. The daily motions of the heavens, he reasoned, could be better explained by a rotating Earth.

Copernicus concluded that Earth is a planet. He proposed a model of the solar system with the sun at the center. This was a major break from the ancient idea that a motionless Earth lies at the center. Copernicus used circles, which were considered to be the perfect geometric shape, to represent the orbits of the planets. However, the planets seemed to stray from their predicted positions.

Tycho Brahe Tycho Brahe (1546–1601) was born of Danish nobility three years after the death of Copernicus. Brahe became interested in astronomy while viewing a solar eclipse that had been predicted by astronomers. He persuaded King Frederick II to build an observatory near Copenhagen. The telescope had not yet been invented. At the observatory, Brahe designed and built instruments, such as the angle-measuring device shown in Figure 5. He used these instruments for 20 years to measure the locations of the heavenly bodies. **Brahe's observations, especially of Mars, were far more precise than any made previously.** In the last year of his life, Brahe found an able assistant, Johannes Kepler. Kepler kept most of Brahe's observations and put them to exceptional use.

Figure 4 Retrograde Motion When viewed from Earth, Mars moves eastward among the stars each day. Then periodically it appears to stop and reverse direction. This apparent movement, called retrograde motion, occurs because Earth has a faster orbital speed than Mars and overtakes it.

Figure 5 Tycho Brahe in His Observatory Brahe (central figure) is painted on the wall within the arc of a sighting instrument called a quadrant.

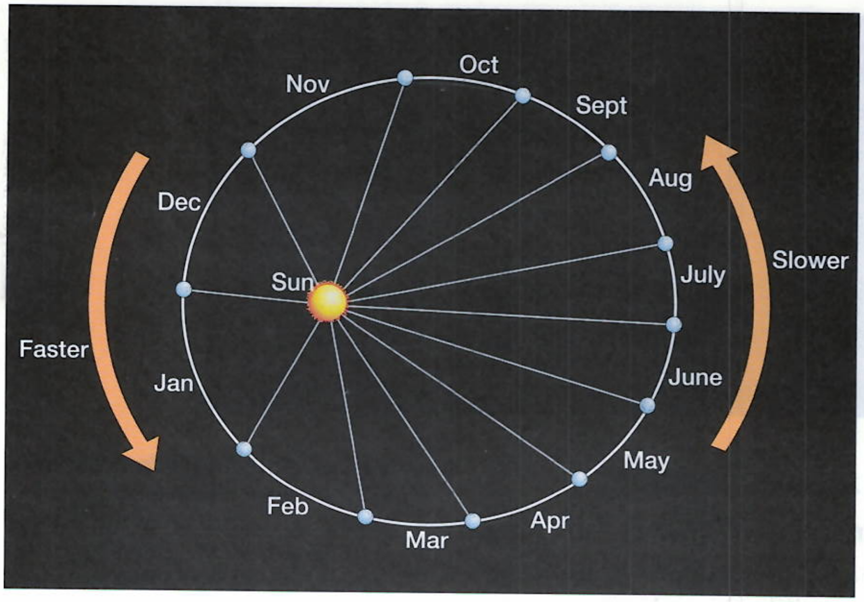


Figure 6 Planet Revolution
A line connecting a planet to the sun would move in such a manner that equal areas are swept out in equal times. Thus, planets revolve slower when they are farther from the sun and faster when they are closer.

Johannes Kepler Copernicus ushered out the old astronomy, and Johannes Kepler (1571–1630) ushered in the new. Kepler had a good mathematical mind and a strong faith in the accuracy of Brahe's work. **Kepler discovered three laws of planetary motion.** The first two laws resulted from his inability to fit Brahe's observations of Mars to a circular orbit. Kepler discovered that the orbit of Mars around the sun is not a perfect circle. Instead, it is an oval-shaped path called an **ellipse.** About the same time, he realized that the speed of Mars in its orbit changes in a predictable way. As Mars approaches the sun, it speeds up. As it moves away from the sun, it slows down.

After decades of work, Kepler summarized three laws of planetary motion:

1. The path of each planet around the sun is an ellipse, with the sun at one focus. The other focus is symmetrically located at the opposite end of the ellipse.
2. Each planet revolves so that an imaginary line connecting it to the sun sweeps over equal areas in equal time intervals, as shown in Figure 6. If a planet is to sweep equal areas in the same amount of time, it must travel more rapidly when it is nearer the sun and more slowly when it is farther from the sun.
3. The square of the length of time it takes a planet to orbit the sun (orbital period) is proportional to the cube of its mean distance to the sun.

In its simplest form, the orbital period of revolution is measured in Earth years. The planet's distance to the sun is expressed in astronomical units. The **astronomical unit** (AU) is the average distance between Earth and the sun. It is about 150 million kilometers.

Using these units, Kepler's third law states that the planet's orbital period squared is equal to its mean solar distance cubed ($T^2 = d^3$). Therefore, the solar distances of the planets can be calculated when their periods of revolution are known. For example, Mars has a period of 1.88 years, which squared equals 3.54. The cube root of 3.54 is 1.52, and that is the distance to Mars in astronomical units shown in Table 1.

Table 1 Period of Revolution and Solar Distances of Planets

Planet	Solar Distance (d) (AU)*	Period (T) (Earth years)
Mercury	0.39	0.24
Venus	0.72	0.62
Earth	1.00	1.00
Mars	1.52	1.88
Jupiter	5.20	11.86
Saturn	9.54	29.46
Uranus	19.18	84.01
Neptune	30.06	164.80
Pluto	39.44	247.70

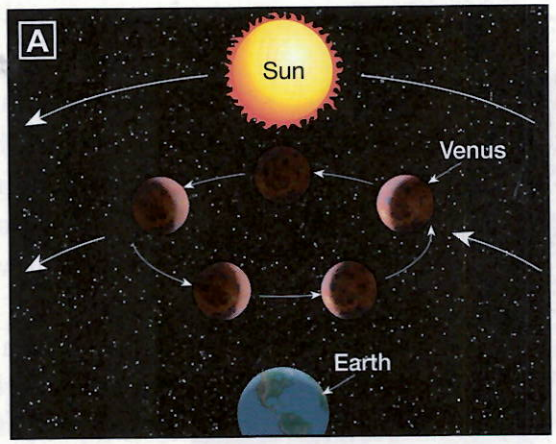
*AU = astronomical unit.

Galileo Galilei Galileo Galilei (1564–1642) was the greatest Italian scientist of the Renaissance. **Galileo's most important contributions were his descriptions of the behavior of moving objects.** All astronomical discoveries before his time were made without the aid of a telescope. In 1609, Galileo heard that a Dutch lens maker had devised a system of lenses that magnified objects. Apparently without ever seeing a telescope, Galileo constructed his own. It magnified distant objects to three times the size seen by the unaided eye.

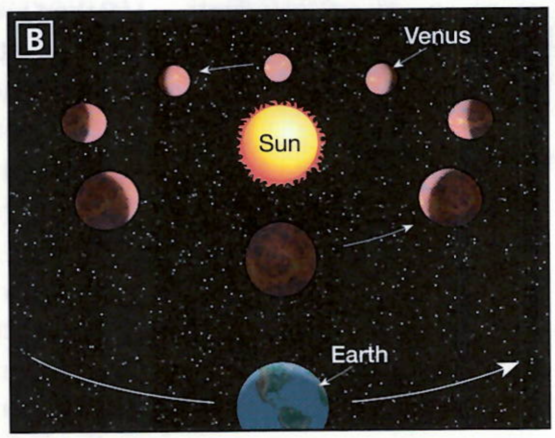
Using the telescope, Galileo was able to view the universe in a new way. He made many important discoveries that supported Copernicus's view of the universe, such as the following:

1. *The discovery of four satellites, or moons, orbiting Jupiter.* This proved that the old idea of Earth being the only center of motion in the universe was wrong. Here, plainly visible, was another center of motion—Jupiter. People who opposed the sun-centered system said that the moon would be left behind if Earth really revolved around the sun. Galileo's discovery disproved this argument.
2. *The discovery that the planets are circular disks, not just points of light, as was previously thought.* This showed that the planets must be Earth-like.
3. *The discovery that Venus has phases just like the moon.* So Venus orbits its source of light—the sun. Galileo saw that Venus appears smallest when it is in full phase and therefore farthest from Earth, as shown in Figure 7.
4. *The discovery that the moon's surface was not smooth.* Galileo saw mountains, craters, and plains. He thought the plains might be bodies of water. This idea was also believed by others, as we can tell from the names given to these features (Sea of Tranquility, Sea of Storms, and so forth).
5. *The discovery that the sun had sunspots, or dark regions.* Galileo tracked the movement of these spots and estimated the rotational period of the sun as just under a month.

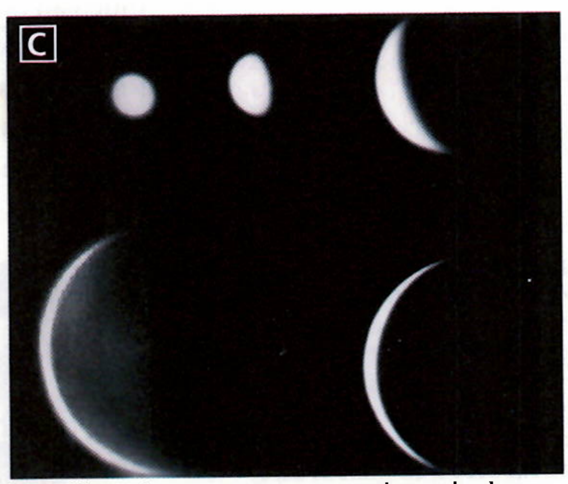
The Solar System Model Evolves



In the Ptolemaic system, the orbit of Venus lies between the sun and Earth.



In the Copernican system, Venus orbits the sun and all its phases are visible from Earth.



As Galileo observed, Venus goes through phases similar to the moon.

Figure 7
Relating Cause and Effect ***In the geocentric model, which phase of Venus would be visible from Earth?***

Figure 8 Sir Isaac Newton

Sir Isaac Newton Sir Isaac Newton (1642–1727) was born in the year of Galileo's death. See Figure 8. Many scientists had attempted to explain the forces involved in planetary motion. Kepler believed that some force pushed the planets along in their orbits. Galileo correctly reasoned that no force is required to keep an object in motion. And he proposed that a moving object will continue to move at a constant speed and in a straight line. This concept is called inertia.

The problem, then, was not to explain the force that keeps the planets moving but rather to determine the force that keeps them from going in a straight line out into space. At the age of 23, Newton described a force that extends from Earth into space and holds the moon in orbit around Earth. **Although others had theorized the existence of such a force, Newton was the first to formulate and test the law of universal gravitation.**

Universal Gravitation According to Newton, every body in the universe attracts every other body with a force that is directly proportional to their masses and inversely proportional to the square of the distance between their centers of mass.

The gravitational force decreases with distance, so that two objects 3 kilometers apart have 3^2, or 9, times less gravitational attraction than if the same objects were 1 kilometer apart.

The law of universal gravitation also states that the greater the mass of the object, the greater is its gravitational force. For example, the mass of the moon creates a gravitational force strong enough to cause ocean tides on Earth. But the tiny mass of a satellite has no measurable effect on Earth. The mass of an object is a measure of the total amount of matter it contains. But more often mass is measured by finding how much an object resists any effort to change its state of motion.

Often we confuse the concept of mass with weight. Weight is the force of gravity acting upon an object. Weight is properly expressed in newtons (N). Therefore, weight varies when gravitational forces change. See Figure 9.

Figure 9 Weight is the force of gravity acting on an object. **A** An astronaut with a mass of 88 kg weighs 863 N on Earth. **B** An astronaut with a mass of 88 kg weighs 141 N on the moon. **Calculating** ***If the same astronaut stood on Mars where the acceleration due to gravity is about 3.7 m/s^2, how much would the astronaut weigh?***

A **Astronaut on Earth**
Mass = 88.0 kg; Weight = 863 N

B **Astronaut on Moon**
Mass = 88.0 kg; Weight = 141 N

Newton proved that the force of gravity, combined with the tendency of a planet to remain in straight-line motion, results in the elliptical orbits that Kepler discovered. Earth, for example, moves forward in its orbit about 30 kilometers each second. During the same second, the force of gravity pulls it toward the sun about 0.5 centimeter. Newton concluded that it is the combination of Earth's forward motion and its "falling" motion that defines its orbit. As Figure 10 shows, if gravity were somehow eliminated, Earth would move in a straight line out into space. If Earth's forward motion suddenly stopped, gravity would pull it directly toward the sun.

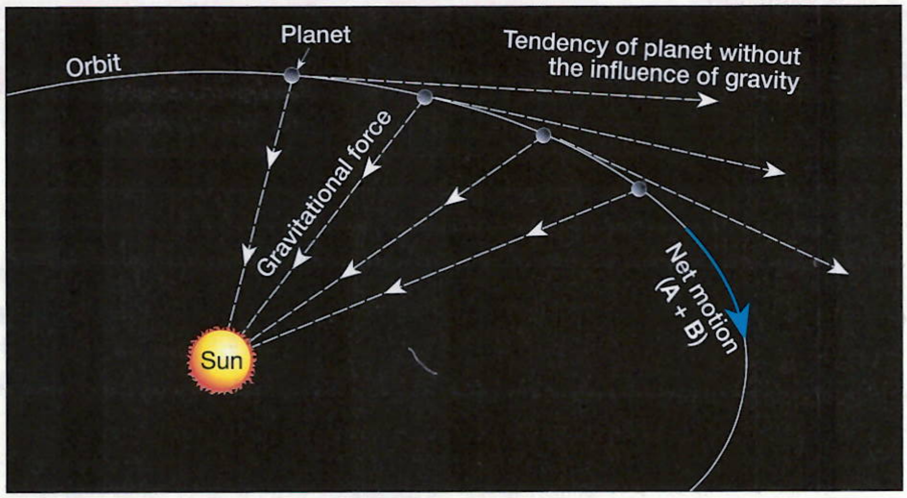


Figure 10 Without the influence of gravity, planets would move in a straight line out into space.

Newton used the law of universal gravitation to redefine Kepler's third law, which states the relationship between the orbital periods of the planets and their solar distances. When restated, Kepler's third law takes into account the masses of the bodies involved and provides a method for determining the mass of a body when the orbit of one of its satellites is known.

Section 22.1 Assessment

Reviewing Concepts

1. Compare and contrast the geocentric and heliocentric models of the universe.
2. What produces the retrograde motion of Mars?
3. What geometric arrangements did Ptolemy use to explain retrograde motion?
4. What major change did Copernicus make in the Ptolemaic system? Why was this change significant?

Critical Thinking

5. **Applying Concepts** What role did the telescope play in Galileo's contributions to science?
6. **Summarizing** In your own words, summarize Kepler's three laws of planetary motion.

Math Practice

7. Use Kepler's third law to show that the distance of a planet whose period is 5 years is 2.9 AU from the sun. Do the same for a planet with a period of 10 years at 4.6 AU from the sun, and a planet with a period of 10 days at 0.09 AU from the sun.

22.2 The Earth-Moon-Sun System

Reading Focus

Key Concepts

- In what ways does Earth move?
- What causes the phases of the moon?
- Why are eclipses relatively rare events?

Vocabulary

- rotation
- revolution
- precession
- perihelion
- aphelion
- perigee
- apogee
- phases of the moon
- solar eclipse
- lunar eclipse

Reading Strategy

Monitoring Your Understanding Copy the flowchart below. As you read, complete it to show how eclipses occur.

Eclipses occur when

the moon comes between Earth and the sun. → Such an event is called a → b. ?

a. ? → Such an event is called a → c. ?

If you gaze away from the city lights on a clear night, it will seem that the stars produce a spherical shell surrounding Earth. This impression seems so real that it is easy to understand why many early Greeks regarded the stars as being fixed to a solid, celestial sphere. People have always been fascinated by the changing positions of the sun and moon in the sky. Prehistoric people, for example, built observatories. The structure known as Stonehenge, shown in Figure 11, was probably an attempt at better solar predictions. At the beginning of summer in the Northern Hemisphere (the summer solstice on June 21 or 22), the rising sun comes up directly above the heel stone of Stonehenge. Besides keeping this calendar, Stonehenge may also have provided a method of determining eclipses. In this section, you'll learn more about the movements of bodies in space that cause events such as eclipses.

Figure 11 On the summer solstice, the sun can be observed rising above the heel stone of Stonehenge, an ancient observatory in England.

Motions of Earth

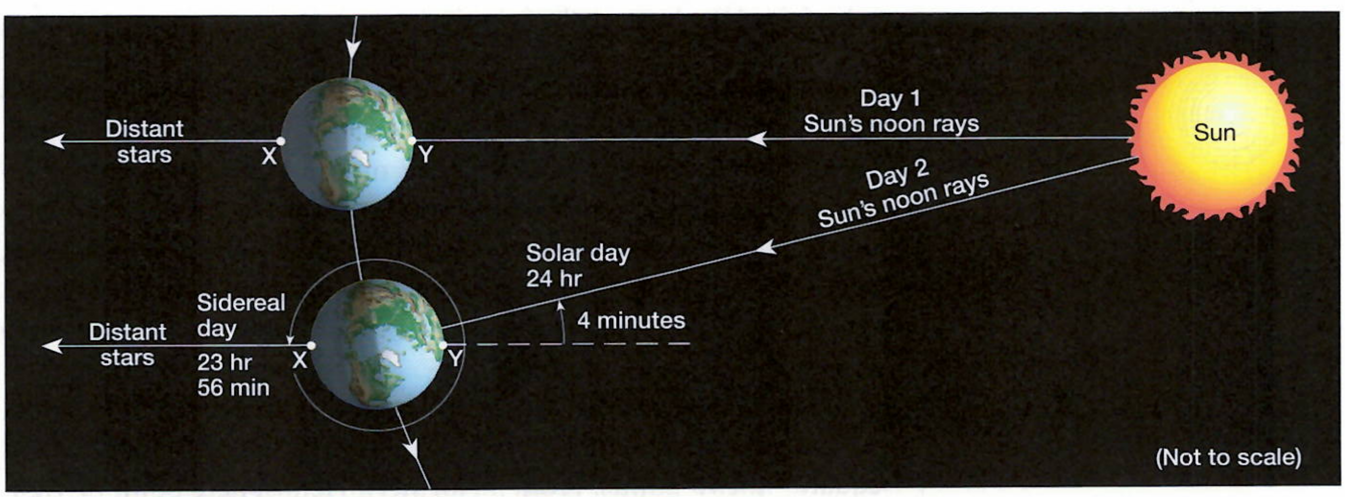
The two main motions of Earth are rotation and revolution. Rotation is the turning, or spinning, of a body on its axis. **Revolution** is the motion of a body, such as a planet or moon, along a path around some point in space. For example, Earth revolves around the sun, and the moon revolves around Earth. Earth also has another very slow motion known as **precession,** which is the slight movement, over a period of 26,000 years, of Earth's axis.

Rotation The main results of Earth's rotation are day and night. Earth's rotation has become a standard method of measuring time because it is so dependable and easy to use. Each rotation equals about 24 hours. You may be surprised to learn that we can measure Earth's rotation in two ways, making two kinds of days. Most familiar is the mean solar day, the time interval from one noon to the next, which averages about 24 hours. Noon is when the sun has reached its zenith, or highest point in the sky.

The sidereal day, on the other hand, is the time it takes for Earth to make one complete rotation (360 degrees) with respect to a star other than our sun. The sidereal day is measured by the time required for a star to reappear at the identical position in the sky where it was observed the day before. The sidereal day has a period of 23 hours, 56 minutes, and 4 seconds (measured in solar time), which is almost 4 minutes shorter than the mean solar day. This difference results because the direction to distant stars barely changes because of Earth's slow revolution along its orbit. The direction to the sun, on the other hand, changes by almost 1 degree each day. This difference is shown in Figure 12.

Why do we use the mean solar day instead of the sidereal day as a measurement of our day? In sidereal time, "noon" occurs four minutes earlier each day. Therefore, after six months, "noon" occurs at "midnight." Astronomers use sidereal time because the stars appear in the same position in the sky every 24 sidereal hours. Usually, an observatory will begin its sidereal day when the position of the spring equinox is directly overhead.

Figure 12 Sidereal Day It takes Earth 23 hours and 56 minutes to make one rotation with respect to the stars (sidereal day). However, after Earth has completed one sidereal day, point Y has not yet returned to the "noon position" with respect to the sun. Earth has to rotate another 4 minutes to complete the solar day.



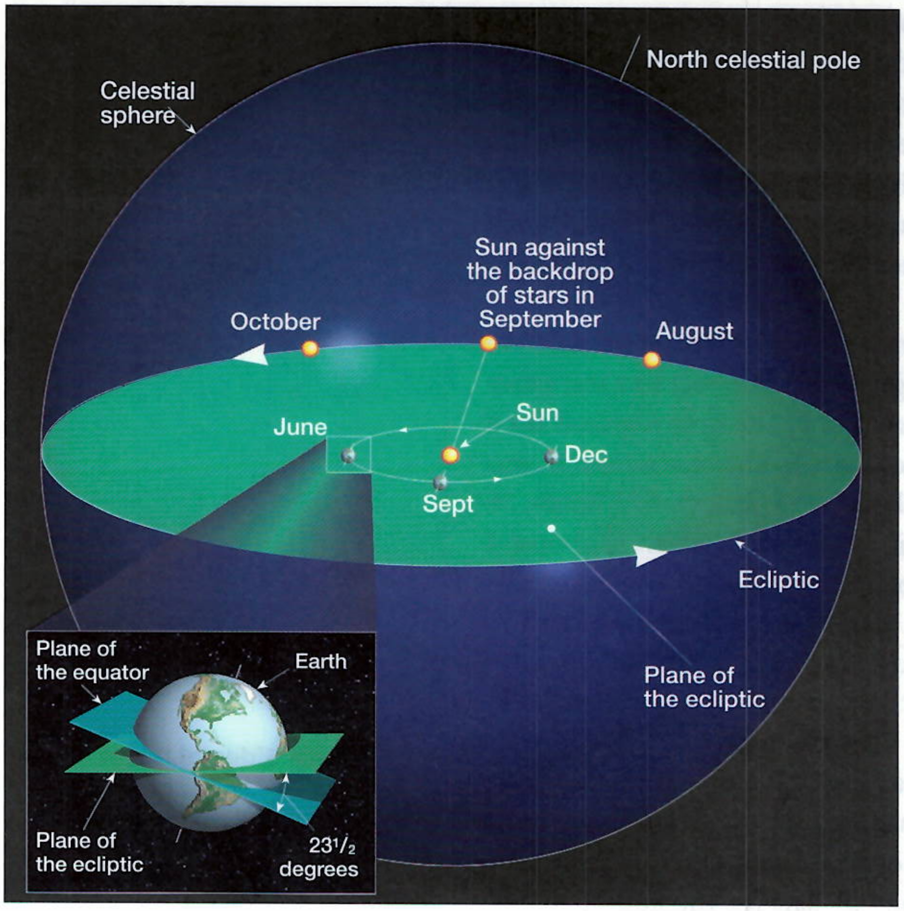


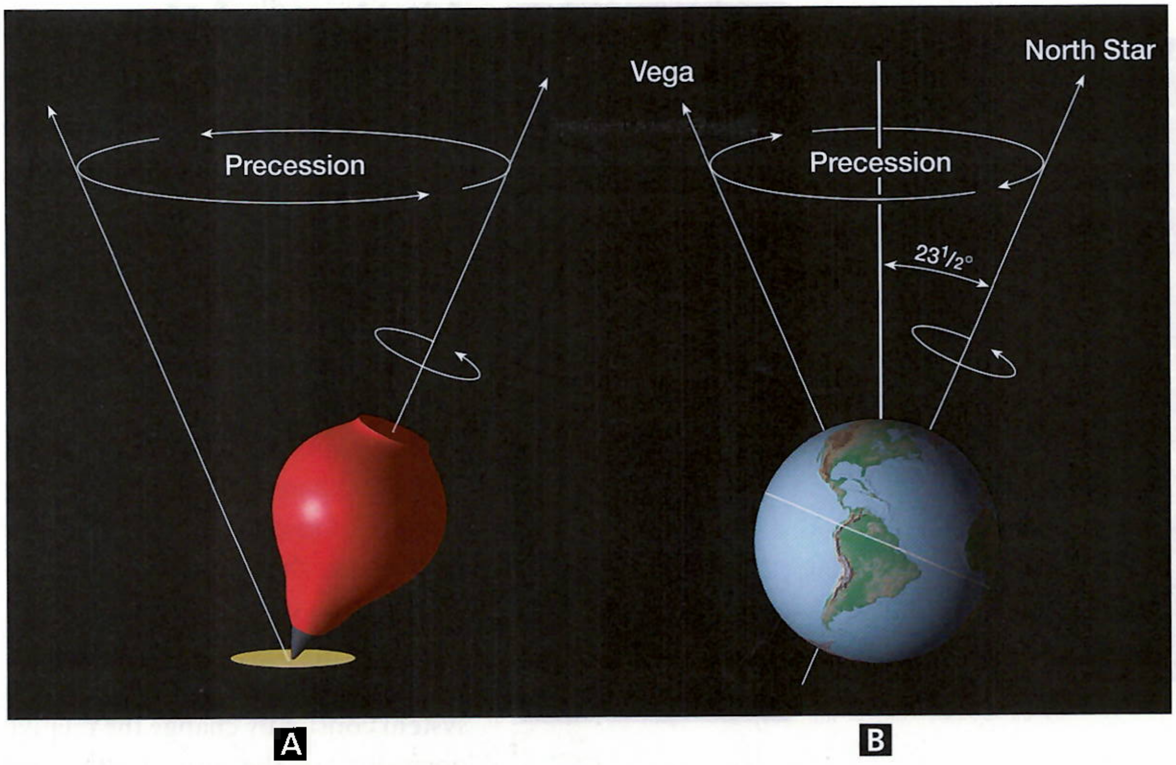
Figure 13 The Ecliptic Earth's orbital motion causes the apparent position of the sun to shift about 1 degree each day on the celestial sphere.

Revolution Earth revolves around the sun in an elliptical orbit at an average speed of 107,000 kilometers per hour. Its average distance from the sun is 150 million kilometers. But because its orbit is an ellipse, Earth's distance from the sun varies. At **perihelion,** Earth is closet to the sun—about 147 million kilometers away. Perihelion occurs about January 3 each year. At **aphelion,** Earth is farthest from the sun—about 152 million kilometers away. Aphelion occurs about July 4. So Earth is farthest from the sun in July and closest to the sun in January.

Because of Earth's annual movement around the sun, each day the sun appears to be displaced among the constellations at a distance equal to about twice its width, or 1 degree. The apparent annual path of the sun against the backdrop of the celestial sphere is called the ecliptic, as shown in Figure 13. Generally, the planets and the moon travel in nearly the same plane as Earth. So their paths on the celestial sphere lie near the ecliptic.

Earth's Axis and Seasons The imaginary plane that connects Earth's orbit with the celestial sphere is called the plane of the ecliptic. From the reference plane, Earth's axis of rotation is tilted about 23.5 degrees. Because of Earth's tilt, the apparent path of the sun and the celestial equator intersect each other at an angle of 23.5 degrees. This angle is very important to Earth's inhabitants. Because of the inclination of Earth's axis to the plane of the ecliptic, Earth has its yearly cycle of seasons.

When the apparent position of the sun is plotted on the celestial sphere over a period of a year's time, its path intersects the celestial equator at two points. From a Northern Hemisphere point of view, these intersections are called the spring equinox (March 20 or 21) and autumn equinox (September 22 or 23). On June 21 or 22, the date of the summer solstice, the sun appears 23.5 degrees north of the celestial equator. Six months later, on December 21–22, the date of the winter solstice, the sun appears 23.5 degrees south of the celestial equator.



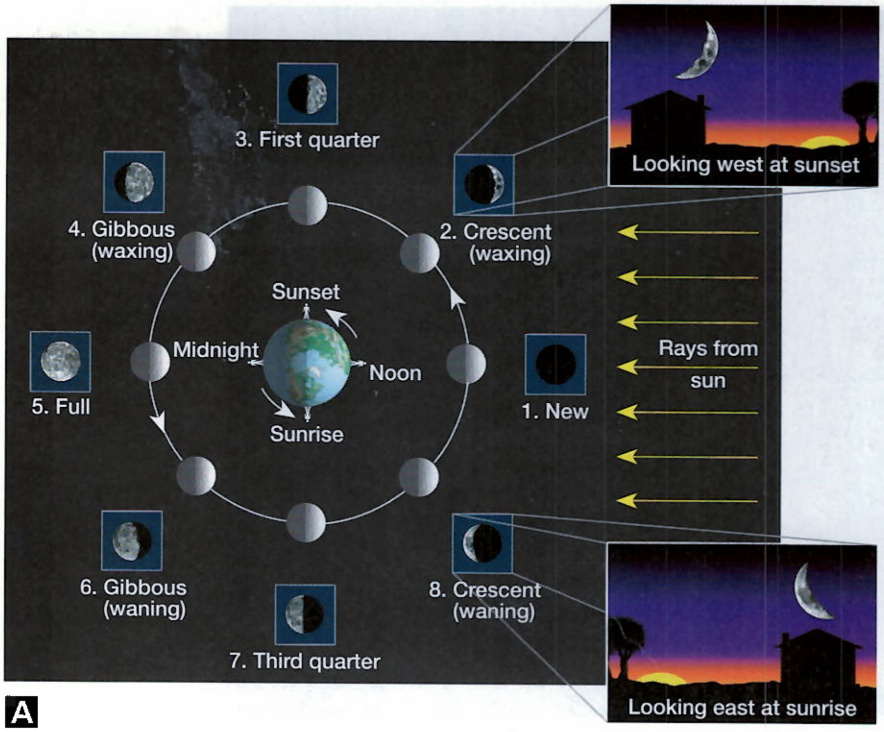
Precession A third and very slow movement of Earth is called precession. Earth's axis maintains approximately the same angle of tilt. But the direction in which the axis points continually changes. As a result, the axis traces a circle on the sky. This movement is very similar to the wobble of a spinning top, as shown in Figure 14A. At the present time, the axis points toward the bright star Polaris. In the year 14,000, it will point toward the bright star Vega, which will then become the North Star, as shown in Figure 14B. The period of precession is 26,000 years. By the year 28,000, Polaris will once again be the North Star.

Precession has only a minor effect on the seasons, because the angle of tilt changes only slightly. It does, however, cause the positions of the seasons (equinox and solstice) to move slightly each year among the stars.

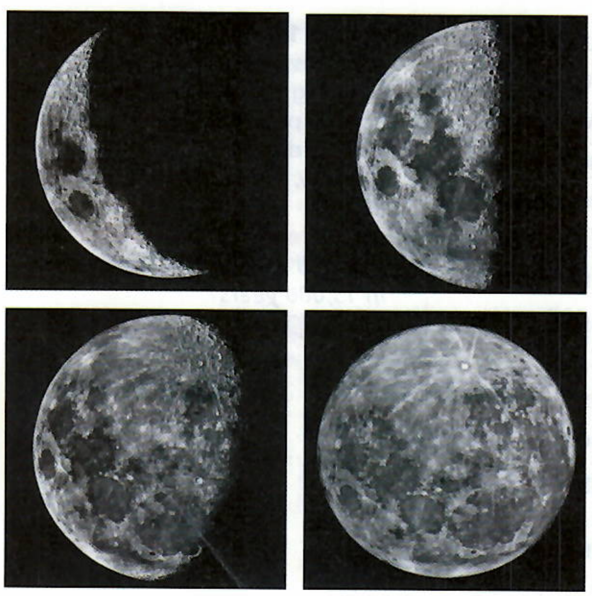
Earth-Sun Motion In addition to its own movements, Earth accompanies the sun as the entire solar system speeds in the direction of the bright star Vega at 20 kilometers per second. Also, the sun, like other nearby stars, revolves around the galaxy. This trip takes 230 million years to traverse at speeds approaching 250 kilometers per second. The galaxies themselves are also in motion. Earth is presently approaching one of its nearest galactic neighbors, the Great Galaxy in Andromeda. The motions of Earth are many and complex, and its speed in space is very great.

Reading Checkpoint ***What is precession?***

Figure 14 Precession
A Precession is similar to a spinning top. It causes the North Pole to point at different parts of the sky during a 26,000-year cycle. **B** Today, the North Pole points to Polaris.
Interpreting Illustrations ***What star will the North Pole point to in 13,000 years?***



A



B

Figure 15 Phases of the Moon
A The outer figures show the phases as seen from Earth.
B Compare these photographs with the diagram.

Motions of the Earth-Moon System

Earth has one natural satellite, the moon. In addition to accompanying Earth in its annual trip around the sun, our moon orbits Earth within a period of about one month. When viewed from above the North Pole, the direction of this motion is counterclockwise. Because the moon's orbit is elliptical, its distance to Earth varies by about 6 percent, averaging 384,401 kilometers. At a point known as **perigee,** the moon is closest to Earth. At a point known as **apogee,** the moon is farthest from Earth.

The motions of the Earth-moon system constantly change the relative positions of the sun, Earth, and moon. This results in changes in the appearance of the moon, as you'll read about next.

Phases of the Moon The first astronomical event to be understood was the regular cycle of the phases of the moon. On a monthly basis, we observe the **phases of the moon** as a change in the amount of the moon that appears lit. Look at the new moon shown in Figure 15A. About two days after the new moon, a thin sliver (crescent phase) appears low in the western sky just after sunset. During the following week, the lighted portion of the moon visible from Earth increases (waxing) to a half circle (first-quarter phase) and can be seen from about noon to midnight. In another week, the complete disk (full-moon phase) can be seen rising in the east as the sun is sinking in the west. During the next two weeks, the percentage of the moon that can be seen steadily declines (waning), until the moon disappears altogether (new-moon phase). The cycle soon begins again with the reappearance of the crescent moon.

Lunar phases are a result of the motion of the moon and the sunlight that is reflected from its surface. See Figure 15B. Half of the moon is illuminated at all times. But to an observer on Earth, the percentage of the bright side that is visible depends on the location of the moon with respect to the sun and Earth. When the moon lies between the sun and Earth, none of its bright side faces Earth.

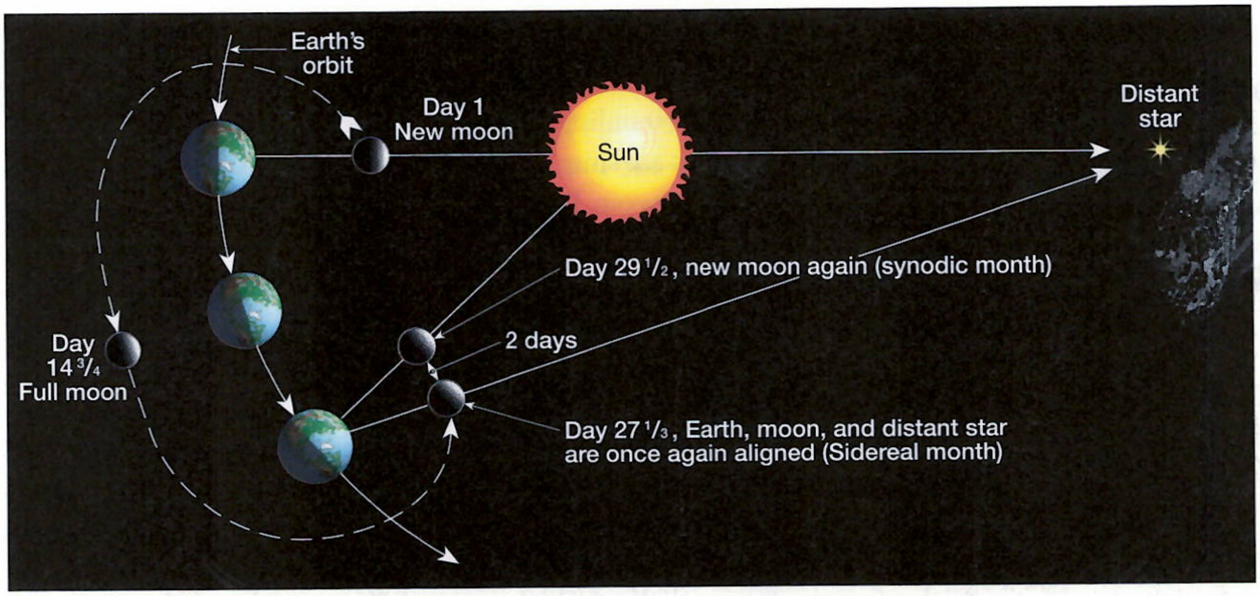


Figure 16 Lunar Motion As the moon orbits Earth, the Earth-moon system also moves in orbit around the sun. Thus, even after the moon makes one revolution around Earth, it has not yet reached its starting point in relation to the stars.

When the moon lies on the side of Earth opposite the sun, all of its lighted side faces Earth. So we see the full moon. At all positions between the new moon and the full moon, a part of the moon's lit side is visible from Earth.

Lunar Motions The cycle of the moon through its phases requires 29 1/2 days, a time span called the synodic month. This cycle was the basis for the first Roman calendar. However, this is the apparent period of the moon's revolution around Earth and not the true period, which takes only 27 1/3 days and is known as the sidereal month. The reason for the difference of nearly two days each cycle is shown in Figure 16. Note that as the moon orbits Earth, the Earth-moon system also moves in an orbit around the sun. Even after the moon has made a complete revolution around Earth, it has not yet reached its starting position, which was directly between the sun and Earth (new-moon phase). The additional motion to reach the starting point takes another two days.

An interesting fact about the motions of the moon is that the moon's period of rotation about its axis and its revolution around Earth are the same. They are both 27 1/3 days. Because of this, the same side of the moon always faces Earth. All of the crewed Apollo missions took place on the side of the moon facing Earth. Only orbiting satellites and astronauts have seen the "back" side of the moon.

Because the moon rotates on its axis only once every 27 1/3 days, any location on its surface experiences periods of daylight and darkness lasting about two weeks. This, along with the absence of an atmosphere, accounts for the high surface temperature of 127°C on the day side of the moon and the low surface temperature of −173°C on its night side.

Reading Checkpoint *Why does the same side of the moon always face Earth?*

Q & A

Q *Why do we sometimes see the moon in daytime?*

A During phases of the lunar cycle other than the full moon, the moon and sun are not directly opposite each other. This makes it possible to see the moon during daylight hours.

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Eclipses

Along with understanding the moon's phases, the early Greeks also realized that eclipses are simply shadow effects. When the moon moves in a line directly between Earth and the sun, it casts a dark shadow on Earth. This produces a **solar eclipse.** This situation occurs during new-moon phases. The moon is eclipsed when it moves within Earth's shadow, producing a **lunar eclipse.** This situation occurs during full-moon phases. Figure 17 illustrates solar and lunar eclipses.

Why doesn't a solar eclipse occur with every new moon and a lunar eclipse with every full moon? They would if the orbit of the moon lay exactly along the plane of Earth's orbit. However, the moon's orbit is inclined about 5 degrees to the plane that contains Earth and the sun. During most new-moon phases, the shadow of the moon misses Earth (passes above or below). During most full-moon phases, the shadow of Earth misses the moon. **During a new-moon or full-moon phase, the moon's orbit must cross the plane of the ecliptic for an eclipse to take place.** Because these conditions are normally met only twice a year, the usual number of eclipses is four. These occur as a set of one solar and one lunar eclipse, followed six months later with another set. Occasionally, the alignment can result in additional eclipses. However, the total number of eclipses in one year isn't more than seven.

Solar and Lunar Eclipse

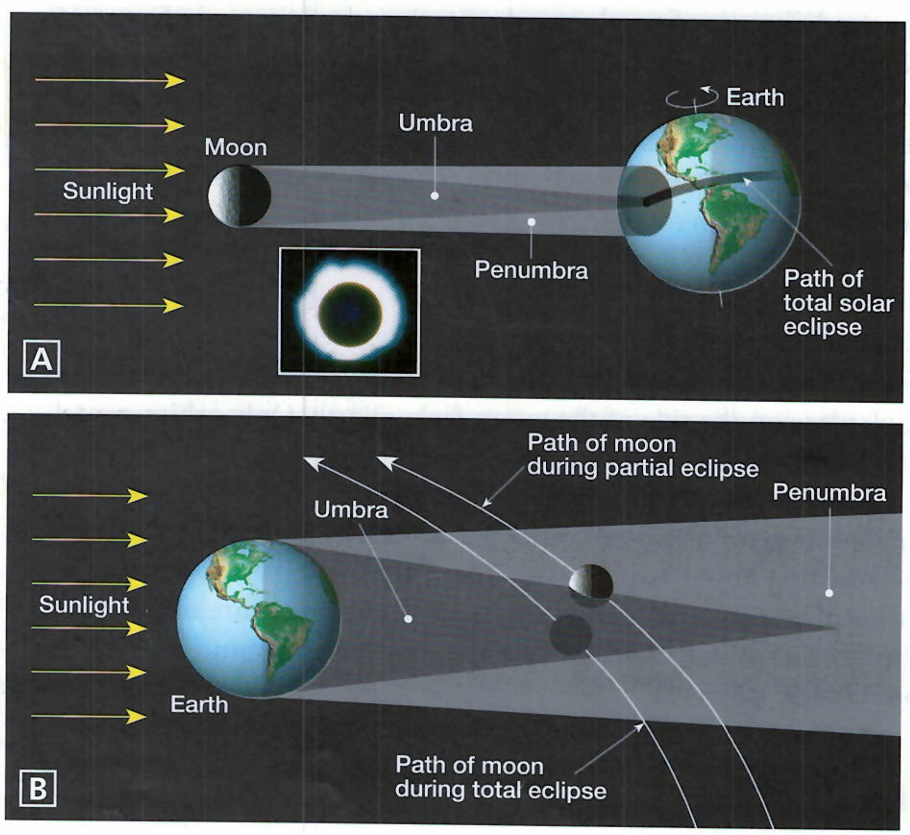


Figure 17 A Observers in the umbra see a total solar eclipse. Those in the penumbra see a partial eclipse. The path of the solar eclipse moves eastward across the globe. The figure shows a total solar eclipse. **B** During a total lunar eclipse, the moon's orbit carries it into Earth's umbra. During a partial eclipse, only a portion of the moon enters the umbra.

During a total lunar eclipse, Earth's circular shadow can be seen moving slowly across the disk of the full moon. When totally eclipsed, the moon is completely within Earth's shadow, but it is still visible as a coppery disk. This happens because Earth's atmosphere bends and transmits some long-wavelength light (red) into its shadow. A total eclipse of the moon can last up to four hours and is visible to anyone on the side of Earth facing the moon.

During a total solar eclipse, the moon casts a circular shadow that is never wider than 275 kilometers, about the size of South Carolina. Anyone observing in this region will see the moon slowly block the sun from view and the sky darken. When the eclipse is almost complete, the temperature sharply drops a few degrees. The solar disk is completely blocked for seven minutes at the most. This happens because the moon's shadow is so small. Then one edge reappears.

When the eclipse is complete, the dark moon is seen covering the complete solar disk. Only the sun's brilliant white outer atmosphere is visible. Total solar eclipses are visible only to people in the dark part of the moon's shadow known as the umbra. A partial eclipse is seen by those in the light portion of the shadow, known as the penumbra.

Partial solar eclipses are more common in the polar regions. In this zone, the penumbra covers the dark umbra of the moon's shadow, just missing Earth. A total solar eclipse is a rare event at any location. The next one that will be visible from the United States will take place on August 21, 2017.

Section 22.2. Assessment

Reviewing Concepts

1. In what ways does Earth move?
2. What phenomena result from Earth's rotation and revolution?
3. What causes the phases of the moon?
4. How does the crescent phase that precedes the new moon differ from the crescent phase that follows the new moon?
5. Why don't eclipses occur during every full-moon or new-moon phase?
6. Describe the locations of the sun, moon, and Earth during a solar eclipse and during a lunar eclipse.

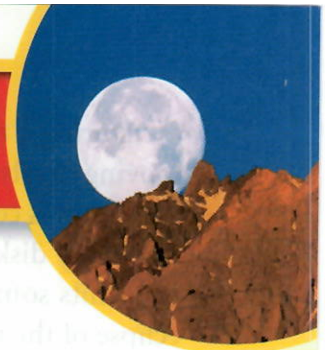
Critical Thinking

7. **Predicting** Currently, Earth is closest to the sun in January (perihelion) and farthest from the sun in July (aphelion). However, 13,000 years from now, precession will cause perihelion to occur in July and aphelion to occur in January. Assuming no other changes, how might this affect average summer temperatures for your location? What about average winter temperatures?

Writing in Science

Firsthand Account Imagine you are an assistant for one of the ancient astronomers. You are present when the astronomer makes an important discovery. Write a firsthand account describing the discovery and its impact on science.

22.3 Earth's Moon



Reading Focus

Key Concepts

- What processes create surface features on the moon?
- How did the moon form?

Vocabulary

- crater
- ray
- mare
- rille
- lunar regolith

Reading Strategy

Sequencing Copy Copy the flowchart below. As you read, fill in the stages leading to the formation of the moon.

Mars-size body impacted Earth. → a. ? → b. ? → c. ?

Earth now has hundreds of satellites. Only one natural satellite, the moon, accompanies us on our annual journey around the sun. Other planets have moons. But our planet-satellite system is unusual in the solar system, because Earth's moon is unusually large compared to its parent planet. The diameter of the moon is 3475 kilometers, about one-fourth of Earth's 12,756 kilometers.

Figure 18 This is what the moon's surface looks like from Earth when viewed through a telescope.

Much of what we know about the moon, shown in Figure 18, comes from data gathered by the *Apollo* moon missions. Six *Apollo* spacecraft landed on the moon between 1969 and 1972. Uncrewed spacecraft such as the *Lunar Prospector* have also explored the moon's surface. From calculation of the moon's mass, we know that its density is 3.3 times that of water. This density is comparable to that of mantle rocks on Earth. But it is considerably less than Earth's average density, which is 5.5 times that of water. Geologists have suggested that this difference can be accounted for if the moon's iron core is small. The gravitational attraction at the lunar surface is one-sixth of that experienced on Earth's surface. (A 150-pound person on Earth weighs only 25 pounds on the moon). This difference allows an astronaut to carry a heavy life-support system easily. An astronaut on the moon could jump six times higher than on Earth.

The Lunar Surface

When Galileo first pointed his telescope toward the moon, he saw two different types of landscape—dark lowlands and bright highlands. Because the dark regions resembled seas on Earth, they were later named maria, which comes from the Latin word for *sea*. Today we know that the moon has no atmosphere or water. Therefore, the moon doesn't have the weathering and erosion that continually change Earth's surface. Also, tectonic forces aren't active on the moon, therefore volcanic eruptions no longer occur. However, because the moon is unprotected by an atmosphere, a different kind of erosion occurs. Tiny particles from space continually bombard its surface and gradually smooth out the landscape. Moon rocks become slightly rounded on top after a long time at the lunar surface. Even so, it is unlikely that the moon has changed very much in the last 3 billion years, except for a few craters.

Craters The most obvious features of the lunar surface are **craters,** which are round depressions in the surface of the moon. There are many craters on the moon. The moon even has craters within craters! The larger craters are about 250 kilometers in diameter, about the width of Indiana. **Most craters were produced by the impact of rapidly moving debris.**

By contrast, Earth has only about a dozen easily recognized impact craters. Friction with Earth's atmosphere burns up small debris before it reaches the ground. Evidence for most of the craters that formed in Earth's history has been destroyed by erosion or tectonic processes.

The formation of an impact crater is modeled in Figure 19. Upon impact, the colliding object compresses the material it strikes. This process is similar to the splash that occurs when a rock is dropped into water. A central peak forms after the impact.

Most of the ejected material lands near the crater, building a rim around it. The heat generated by the impact is enough to melt rock. Astronauts have brought back samples of glass and rock formed when fragments and dust were welded together by the impact.

Formation of a Crater

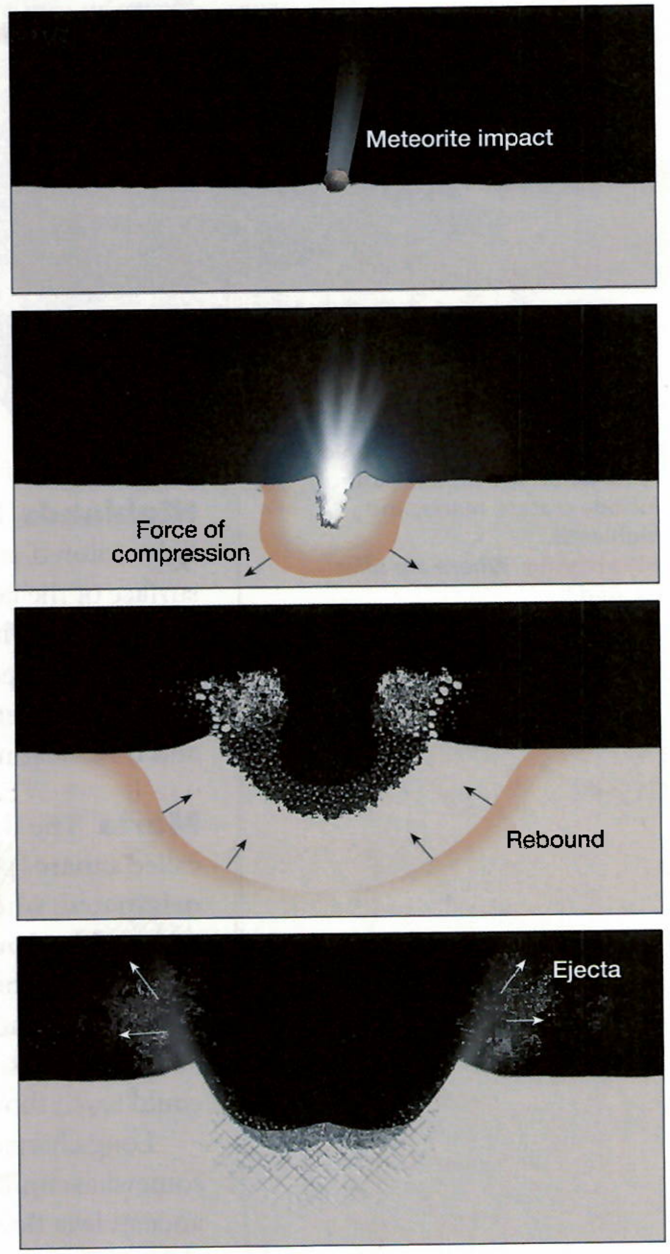


Figure 19 The energy of the rapidly moving meteoroid is transformed into heat energy. Rock compresses, then quickly rebounds. The rebounding rock causes debris to be ejected from the crater.

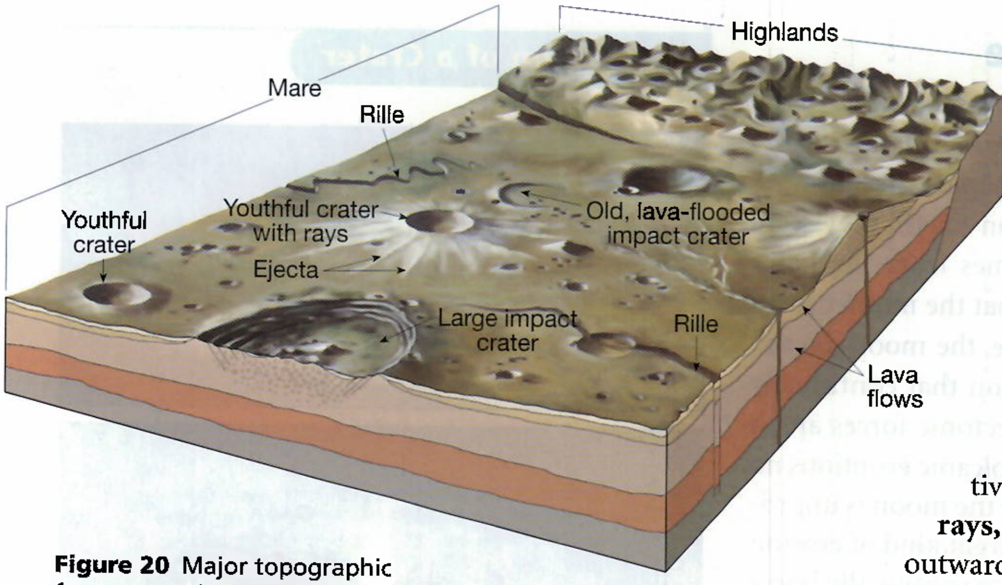


Figure 20 Major topographic features on the moon's surface include craters, maria, and highlands.
Identifying ***Where are rilles located?***

A meteoroid only 3 meters in diameter can blast out a 150-meter-wide crater. A few of the large craters, such as those named Kepler and Copernicus, formed from the impact of bodies 1 kilometer or more in diameter. These two large craters are thought to be relatively young because of the bright **rays,** or splash marks that radiate outward for hundreds of kilometers.

Highlands Most of the lunar surface is made up of densely pitted, light-colored areas known as highlands. In fact, highlands cover the surface of the far side of the moon. The same side of the moon always faces Earth. Within the highland regions are mountain ranges. The highest lunar peaks reach elevations of almost 8 kilometers. This is only 1 kilometer lower than Mount Everest. Figure 20 shows highlands and other features of the moon.

Maria The dark, relatively smooth area on the moon's surface is called a **mare** (plural: maria). **Maria, ancient beds of basaltic lava, originated when asteroids punctured the lunar surface, letting magma bleed out.** Apparently the craters were flooded with layer upon layer of very fluid basaltic lava somewhat resembling the Columbia Plateau in the northwestern United States. The lava flows are often over 30 meters thick. The total thickness of the material that fills the maria could reach thousands of meters.

Long channels called **rilles** are associated with maria. Rilles look somewhat similar to valleys or trenches. Rilles may be the remnants of ancient lava flows.

Regolith All lunar terrains are mantled with a layer of gray debris derived from a few billion years of bombardment from meteorites. This soil-like layer, called **lunar regolith,** is composed of igneous rocks, glass beads, and fine lunar dust. In the maria that have been explored by *Apollo* astronauts, the lunar regolith is just over 3 meters thick.

Reading Checkpoint ***What is lunar regolith?***

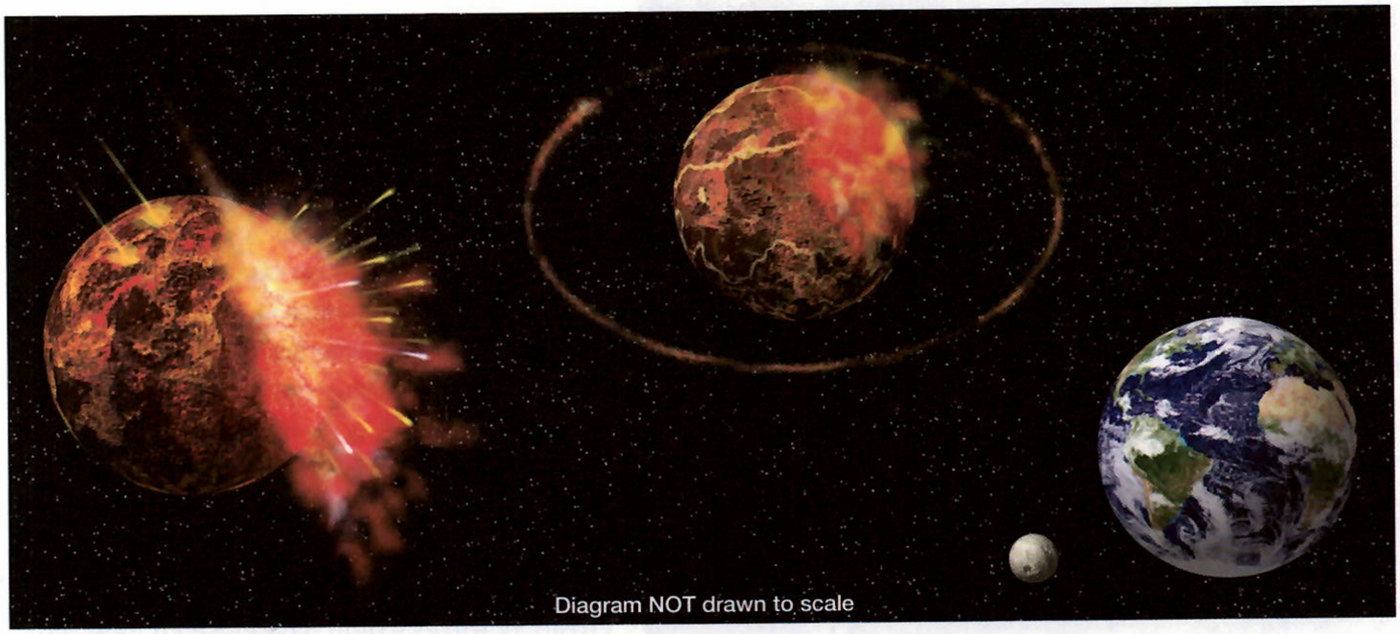


Figure 21 The moon may have formed when a large object collided with Earth. The resulting debris was ejected into space. The debris began orbiting around Earth and eventually united to form the moon.

Lunar History

The moon is our nearest planetary neighbor. Although astronauts have walked on its surface, much is still unknown about its origin. **The most widely accepted model for the origin of the moon is that when the solar system was forming, a body the size of Mars impacted Earth.** The impact, shown in Figure 21, would have liquefied Earth's surface and ejected huge quantities of crustal and mantle rock from an infant Earth. A portion of this ejected debris would have entered an orbit around Earth where it combined to form the moon.

The giant-impact hypothesis is consistent with other facts known about the moon. The ejected material would have been mostly iron-poor mantle and crustal rocks. These would account for the lack of a sizable iron core on the moon. The ejected material would have remained in orbit long enough to have lost the water that the moon lacks. Despite this supporting evidence, some questions remain unanswered.

Geologists have worked out the basic details of the moon's later history. One of their methods is to observe variations in crater density (the number of craters per unit area). The greater the crater density, the older the surface must be. From such evidence, scientists concluded that the moon evolved in three phases—the original crust (highlands), maria basins, and rayed craters.

During its early history, the moon was continually impacted as it swept up debris. This continuous attack, combined with radioactive decay, generated enough heat to melt the moon's outer shell and possibly the interior as well. Remnants of this original crust occupy the densely cratered highlands. These highlands have been estimated to be as much as 4.5 billion years old, about the same age as Earth.

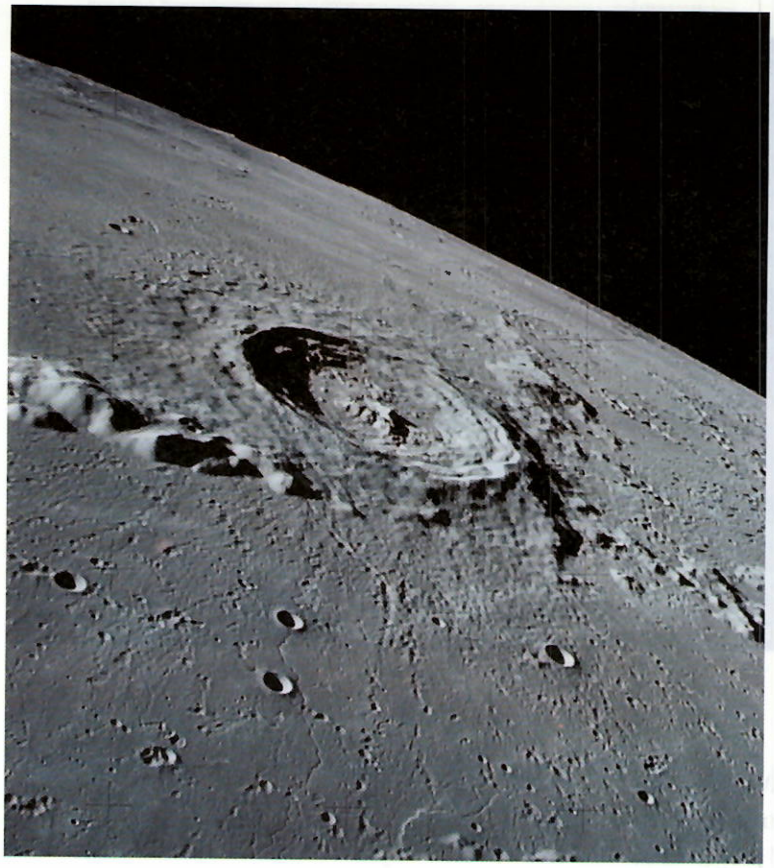


Figure 22 Rayed craters such as Copernicus were the last major features to form on the moon.

One important event in the moon's evolution was the formation of maria basins. Radiometric dating of the maria basalts puts their age between 3.2 billion and 3.8 billion years, about a billion years younger than the initial crust. In places, the lava flows overlap the highlands, which also explains the younger age of the maria deposits.

The last prominent features to form were the rayed craters. Material ejected from these young depressions is clearly seen covering the surface of the maria and many older rayless craters. Even a relatively young crater like Copernicus, shown in Figure 22, must be millions of years old. If it had formed on Earth, erosional forces would have erased it long ago. If photographs of the moon taken several hundreds of millions of years ago were available, they would show that the moon has changed little. The moon is an inactive body wandering through space and time.

Section 22.3 Assessment

Reviewing Concepts

1. How do craters form?
2. How did maria originate?
3. What are the stages that formed the moon?

Critical Thinking

4. **Identifying** On Earth, the four major spheres (atmosphere, hydrosphere, solid Earth, and biosphere) interact as a system. Which of these spheres are absent, or nearly absent, on the moon? Based on your answer, identify at least five processes that operate on Earth but not on the moon.
5. **Inferring** Why are craters more common on the moon than on Earth, even though the moon is a much smaller target?

Connecting Concepts

Scientific Evidence Write a paragraph explaining what evidence scientists use to reconstruct the history of the moon.

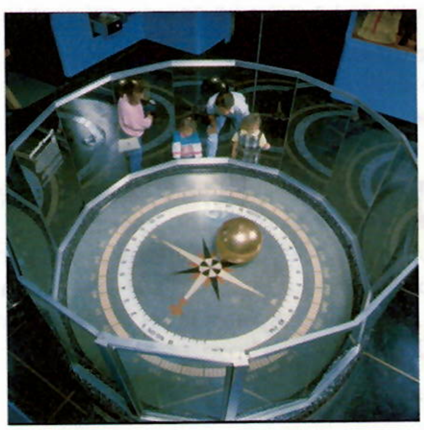
understanding **EARTH**

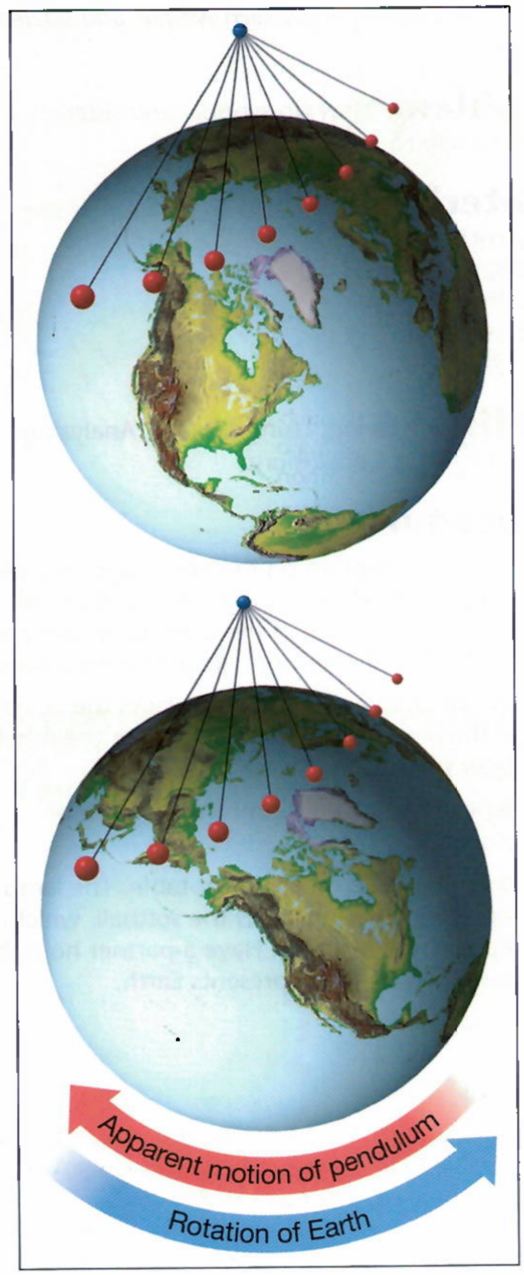
Foucault's Experiment

Earth rotates on its axis once each day to produce periods of daylight and darkness. However, day and night and the apparent motions of the stars can be accounted for equally well by a sun and celestial sphere that revolve around a stationary Earth. Copernicus realized that a rotating Earth greatly simplified the existing model of the universe. He was unable, however, to prove that Earth rotates. The first real proof was presented 300 years after his death by the French physicist Jean Foucault.

The Swinging Pendulum

In 1851, Foucault used a free-swinging pendulum to demonstrate that Earth does, in fact, turn on its axis. To picture Foucault's experiment, imagine a large pendulum swinging over the North Pole, as shown in the illustration on this page. Keep in mind that once a pendulum is put into motion, it continues swinging in the same plane unless acted upon by some outside force. Assume that a sharp point is attached to the bottom of this pendulum, marking the snow as it swings. If we were to observe the marks made by the point, we would see that the pendulum is slowly but continually changing position. At the end of 24 hours, the pendulum would have returned to its starting position.





Evidence of Earth's Rotation

No outside force acted on the pendulum to change its position. So what we observed must have been Earth rotating beneath the pendulum. Foucault conducted a similar experiment when he suspended a long pendulum from the dome of the Pantheon in Paris. Today, Foucault pendulums can be found in some museums to re-create this famous scientific experiment.

Exploration Lab

Modeling Synodic and Sidereal Months

The time interval required for the moon to complete a full cycle of phases is 29.5 days, or one synodic month. The true period of the moon's revolution around Earth, however, takes only 27.3 days and is known as the sidereal month. In this lab, you will model the differences between synodic and sidereal months.

Problem How do synodic and sidereal months differ?

Materials

- pencil
- paper
- lamp
- basketball
- softball

Skills Observing, Using Models, Analyzing Data, Drawing Conclusions

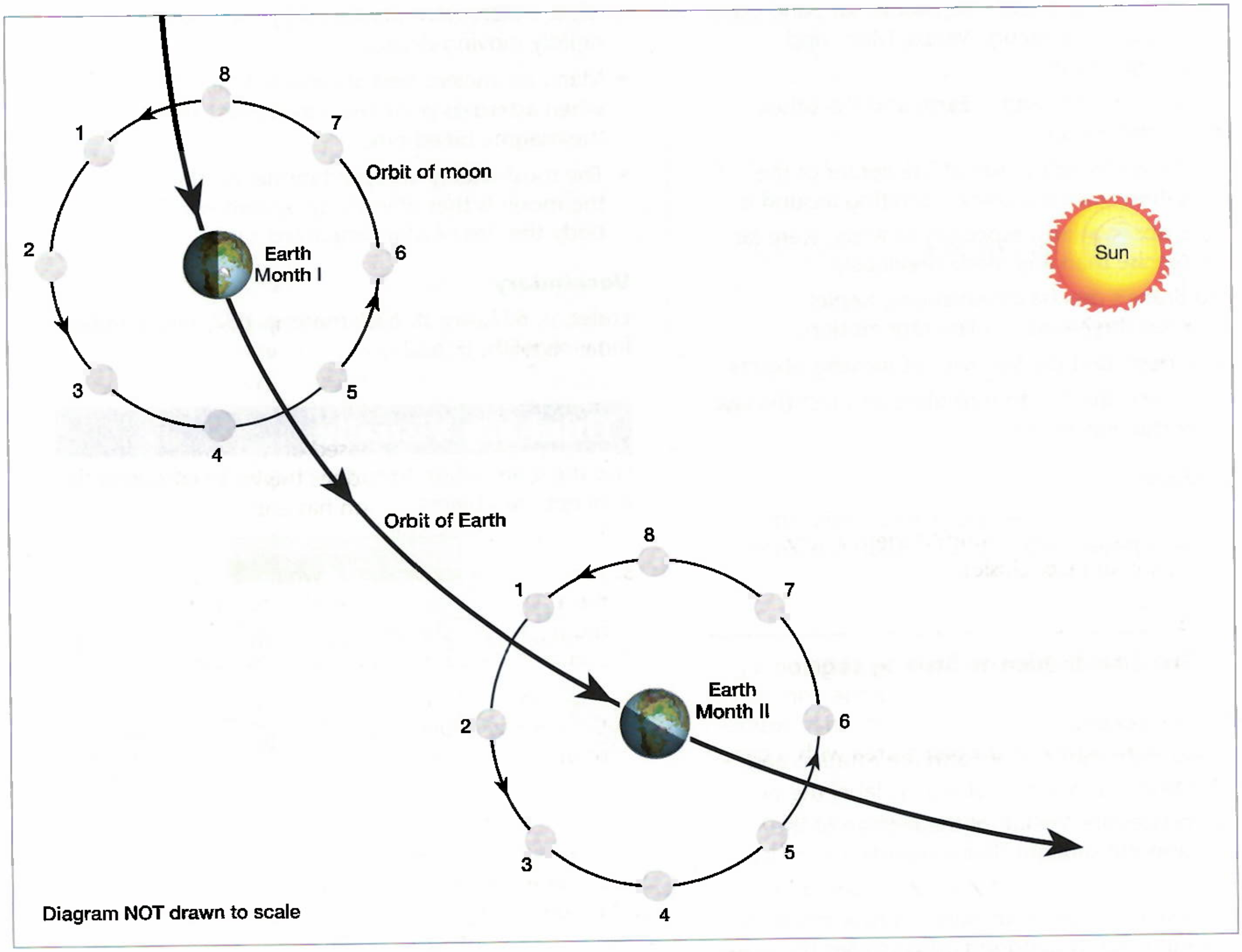
Procedure

1. Copy the diagram on the next page on a piece of paper. In Month 1, indicate the dark half of the moon on each of the eight lunar positions by shading the appropriate area with a pencil.
2. On the diagram of Month 1, label the position of the new moon. Do the same for the other lunar phases.
3. Repeat Steps 1 and 2 for the diagram of Month 2.
4. Place the lamp on a desk or table. The lamp represents the sun. Hold the softball, which represents the moon. Have a partner hold the basketball, which represents Earth.
5. Stand so that the "moon" is in the position of the new-moon phase in Month 1, relative to "Earth" and the "sun." Revolve the moon around Earth while at the same time moving both Earth and the moon to Month 2. Stop at the same numbered position at which you began. Use the diagrams to guide your movements.

Analyze and Conclude

1. **Using Models** After one complete revolution beginning at the new-moon phase in Month 1, in what position is the moon located in Month 2?
2. **Interpreting Data** Based on your answer to the previous question, does this position occur before or after the moon has completed one full cycle of phases?
3. **Identifying** In Month 2, what position represents the new-moon phase? When the moon reaches this position, will it have completed a synodic or sidereal month?
4. **Summarizing** In your own words, explain the difference between a sidereal and synodic month.

Go Further With your partner's help, use the lamp, softball, and basketball to model the positions of the sun, Earth, and moon during a lunar eclipse and a solar eclipse. On your diagram, label the position of the moon during each eclipse.


8
7
1
Orbit of moon
2
Earth
Month I
6
Sun
3
5
4
Orbit of Earth
8
1
7
Earth
Month II
2
6
3
5
4
Diagram NOT drawn to scale

CHAPTER 22

Study Guide

22.1 Early Astronomy

Key Concepts

- In the geocentric model, the moon, sun, and the known planets—Mercury, Venus, Mars, and Jupiter—orbit Earth.
- In the heliocentric model, Earth and the other planets orbit the sun.
- Copernicus placed the sun at the center of the solar system, with the planets orbiting around it.
- Brahe's observations, especially of Mars, were far more precise than any made previously.
- Using Brahe's precise observations, Kepler discovered three laws of planetary motion.
- Galileo described the behavior of moving objects.
- Newton was the first to formulate and test the law of universal gravitation.

Vocabulary

astronomy, *p. 614;* geocentric, *p. 615;* heliocentric, *p. 616;* retrograde motion, *p. 616;* ellipse, *p. 618;* astronomical unit (AU), *p. 618*

22.2 The Earth-Moon-Sun System

Key Concepts

- The two main motions of Earth are rotation and revolution.
- Lunar phases are a result of the motion of the moon and the sunlight that is reflected from its surface.
- An eclipse can only occur during a new moon or full moon when the moon's orbit crosses the plane of the ecliptic.

Vocabulary

rotation, *p. 622;* revolution, *p. 622;* precession, *p. 622;* perihelion, *p. 624;* aphelion, *p. 624;* perigee, *p. 626;* apogee, *p. 626;* phases of the moon, *p. 626;* solar eclipse, *p. 628;* lunar eclipse, *p. 628*

22.3 Earth's Moon

Key Concepts

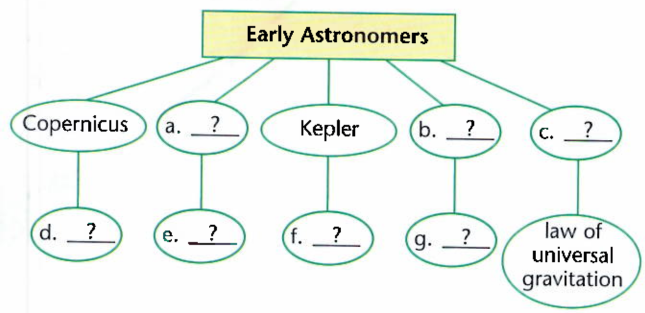
- Most craters were produced by the impact of rapidly moving debris.
- Mare, an ancient bed of basaltic lava, originated when asteroids punctured the lunar surface, letting the magma bleed out.
- The most widely accepted model for the origin of the moon is that when solar system was forming, a body the size of Mars impacted Earth.

Vocabulary

crater, *p. 631;* ray, *p. 632;* mare, *p. 632;* rille, *p. 632;* lunar regolith, *p. 632*

Thinking Visually

Use the information from the chapter to complete the concept map below.



CHAPTER 22

Assessment

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Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Which Greek first proposed that the sun was the center of the universe?
   a. Aristotle
   b. Aristarchus
   c. Anaxogoras
   d. Hipparchus
2. One astronomical unit averages about
   a. 93 million kilometers.
   b. 150 million kilometers.
   c. 210 million kilometers.
   d. 300 million kilometers.
3. During which month is Earth farthest from the sun?
   a. January
   b. April
   c. July
   d. October
4. In the year 14,000, Earth's axis will point toward
   a. Polaris.
   b. Vega.
   c. the sun.
   d. the moon.
5. When is the moon nearest to Earth during its orbit?
   a. at apogee
   b. at perihelion
   c. during an eclipse
   d. at perigee
6. What type of eclipse occurs when the moon casts its shadow on Earth?
   a. lunar
   b. sidereal
   c. solar
   d. synodic
7. During the period that the moon's phases are changing from new to full, the moon is
   a. waning.
   b. approaching Earth.
   c. waxing.
   d. receding from Earth.
8. The large, dark regions on the moon are called
   a. highlands.
   b. craters.
   c. mountains.
   d. maria.
9. Rilles are associated with which of the following lunar features?
   a. craters
   b. maria
   c. rays
   d. highlands
10. The oldest lunar features are
    a. highlands.
    b. rayed craters.
    c. rilles.
    d. maria.

Understanding Concepts

11. List three accomplishments of Hipparchus.
12. Describe how Eratosthenes measured the size of Earth.
13. What was Tycho Brahe's contribution to science?
14. Use Kepler's third law ($T^2 = d^3$) to determine the period of a planet whose solar distance is 10 AU.
15. What is an astronomical unit?
16. Newton learned that the orbits of planets are the results of what two forces?
17. Explain the difference between the mean solar day and the sidereal day.
18. What is the approximate length of the cycle of the phases of the moon?
19. What phase of the moon occurs approximately one week after the new moon?
20. How many eclipses normally occur each year?
21. How long can a total eclipse of the moon last? A total eclipse of the sun?
22. Describe three features found on the moon's surface.
23. Briefly outline the history of the moon.

Assessment *continued*

Critical Thinking

24. **Drawing Conclusions** Does Earth move faster in its orbit near perihelion (January) or near aphelion (July)? Based on your answer, is the solar day longest in January or July?

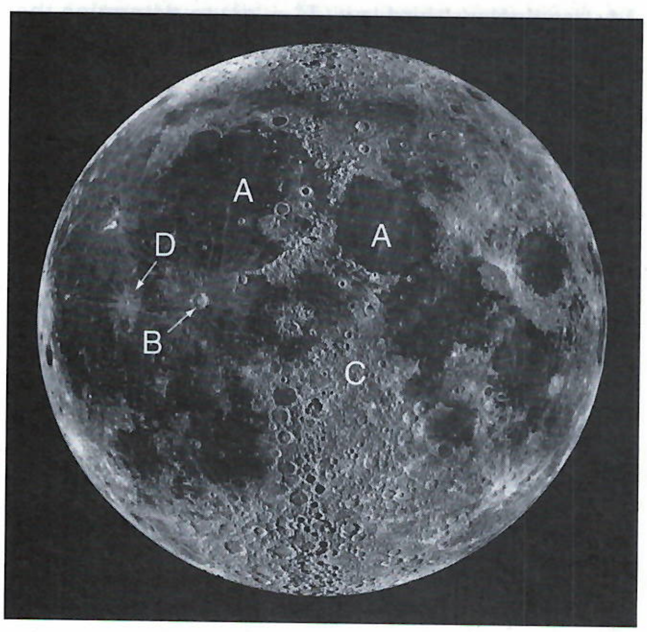
25. **Predicting** The moon rotates very slowly on its axis. Predict how this affects the lunar surface temperature.

26. **Applying Concepts** Solar eclipses are slightly more common than lunar eclipses. Why then is it more likely that your region of the country will experience a lunar eclipse?

27. **Making Generalizations** In what ways do the interactions between Earth and its moon influence the Earth-moon system? If Earth did not have a moon, would the atmosphere, hydrosphere, solid Earth, and biosphere be any different? Explain.

Analyzing Data

Use the photograph below to answer Questions 28–30.



28. **Interpreting Data** What feature exists at point A? How did this feature likely form?

29. **Identifying** Which point represents a ray? Which point represents highlands?

30. **Inferring** What is the oldest feature in the photograph? How do you know?

Concepts in Action

31. **Relating Cause and Effect** How does the fact that Venus appears full when it is smallest support Copernicus's view rather than the Ptolemaic system?

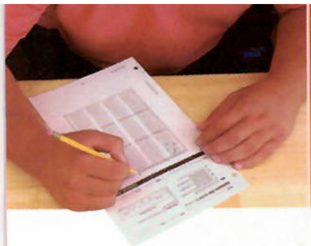
32. **Explaining** Explain how Galileo's discovery of a rotating sun supported the heliocentric model.

33. **Identifying** What is the result of the moon's period of rotation and revolution being the same?

34. **Applying Concepts** How is crater density used in the relative dating of features on the moon?

Performance-Based Assessment

Observing Record at least four observations of the moon over the next two weeks. Sketch the moon at each observation. Use shading to show the phase you see. Note the date and time of each observation. Afterwards, write a paragraph describing how the size and shape of the lit portion of the moon changed over the length of your observations.



Standardized Test Prep

Test-Taking Tip

Eliminating Unreasonable Answers

When you answer a multiple-choice question, you can often eliminate at least one answer because it is clearly incorrect. If you eliminate one or more choices, you increase your odds of choosing the correct answer. In the question below, you can immediately eliminate choice A because the moon does not have rivers on its surface. Clearly, choices B and D cannot both be true because they relate to the same phenomenon. You can eliminate both of these choices because volcanic activity is not currently occurring on the moon. The remaining choice, C, must be the correct answer.

The most important forces currently modifying the moon's surface are

(A) rivers.
(B) lava flows.
(C) tiny particles from space.
(D) volcanoes.

1. The Ptolemy system proposed that
   (A) Earth revolved around the sun.
   (B) the sun was the center of the universe.
   (C) Earth was a wanderer.
   (D) Earth was the center of the universe.

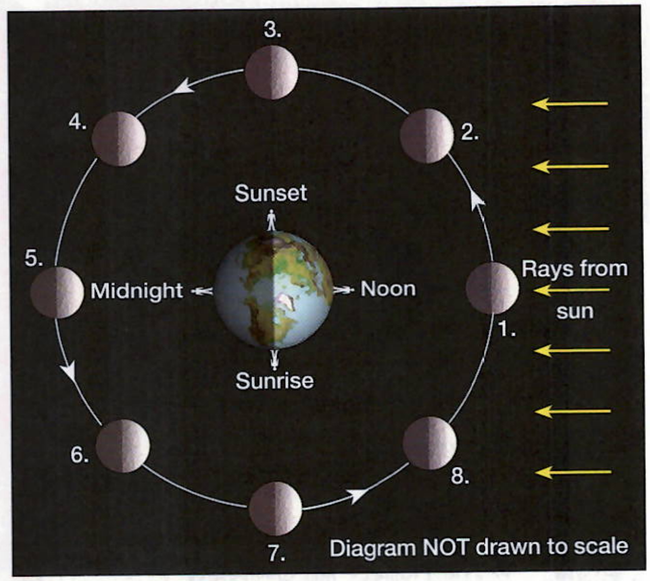
2. What is the shape of a planet's orbit?
   (A) circular
   (B) irregular
   (C) elliptical
   (D) constantly changing

3. Explain why the planets appear to have retrograde motion.

4. List and describe four motions that Earth continuously experiences.

5. Compare and contrast an umbra and a penumbra.

Use the diagram below to answer Questions 6 and 7.



6. Select the number that illustrates the moon's position in its orbit for each of the following phases: full, third quarter, waxing crescent, new, waning.

7. What number represents the position of the moon during a lunar eclipse? A solar eclipse?

CHAPTER 23

Touring Our Solar System

CONCEPTS in Action

Exploration Lab
Modeling the Solar System

Earth as A System
Is Earth on a Collision Course?

GEODe Earth Science
Astronomy
↳ The Planets: An Overview
Calculating Your Age and Weight on Other Planets
Earth's Moon
A Brief Tour of the Planets

Discovery Channel School

Video Field Trip

Heavenly Bodies

Take a field trip through our solar system with Discovery Channel and learn about some of our neighboring planets.

1. Name one reason scientists think it is possible that life has existed on Mars.
2. Why are scientists certain that no life can exist on Saturn, Jupiter, Neptune, and Uranus?

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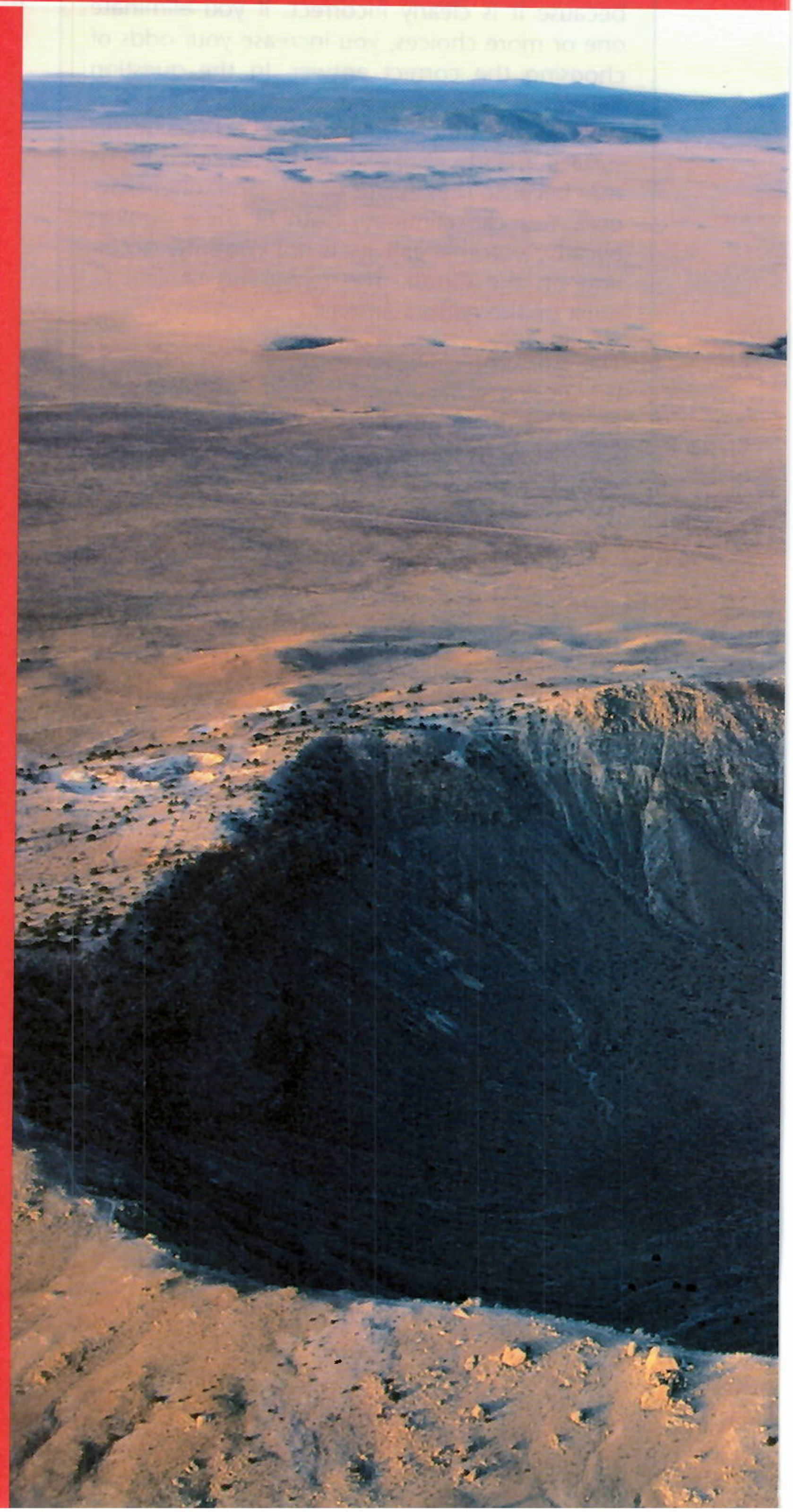
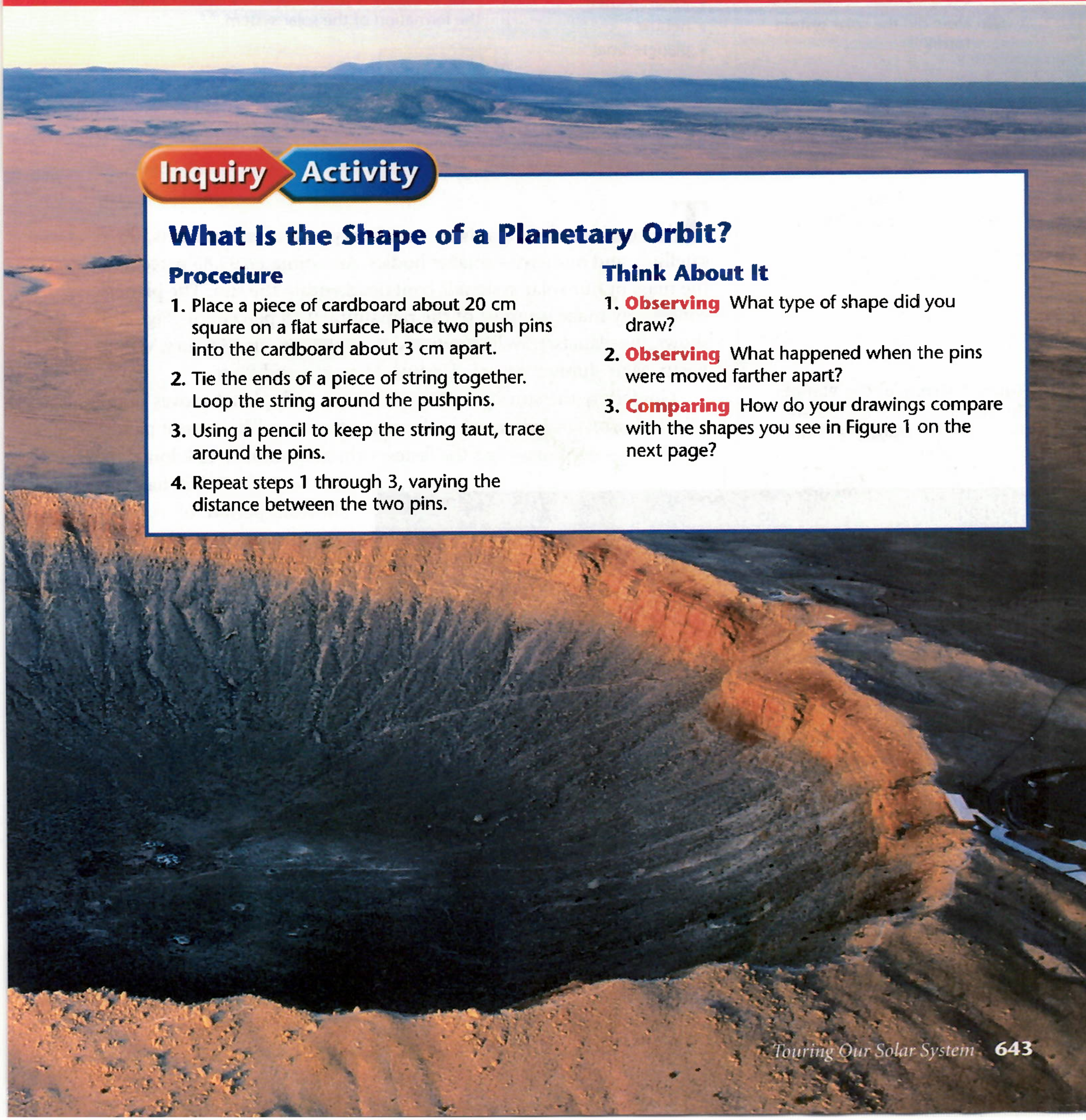


Meteor Crater, near Winslow, Arizona, is ▶ about 1.2 kilometers across and 170 meters deep. The solar system is cluttered with meteoroids and other objects that can strike Earth with explosive force.

Chapter Preview



Inquiry Activity

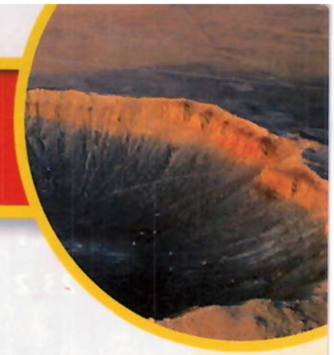
What Is the Shape of a Planetary Orbit?

Procedure

1. Place a piece of cardboard about 20 cm square on a flat surface. Place two push pins into the cardboard about 3 cm apart.
2. Tie the ends of a piece of string together. Loop the string around the pushpins.
3. Using a pencil to keep the string taut, trace around the pins.
4. Repeat steps 1 through 3, varying the distance between the two pins.

Think About It

1. **Observing** What type of shape did you draw?
2. **Observing** What happened when the pins were moved farther apart?
3. **Comparing** How do your drawings compare with the shapes you see in Figure 1 on the next page?



23.1 The Solar System

Reading Focus

Key Concepts

- How do terrestrial planets differ from Jovian planets?
- How did the solar system form?

Vocabulary

- terrestrial planet
- Jovian planet
- nebula
- planetesimal

Reading Strategy

Relating Text and Diagrams As you read, refer to Figure 3 to complete the flowchart on the formation of the solar system.

Cloud of dust and gas began rotating. → a. ? → b. ? → c. ?

The sun is the hub of a huge rotating system of nine planets, their satellites, and numerous smaller bodies. An estimated 99.85 percent of the mass of our solar system is contained within the sun. The planets collectively make up most of the remaining 0.15 percent. As Figure 1 shows, the planets, traveling outward from the sun, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.

Guided by the sun's gravitational force, each planet moves in an elliptical orbit, and all travel in the same direction. The nearest planet to the sun—Mercury—has the fastest orbital motion at 48 kilometers per second, and it has the shortest period of revolution. By contrast, the most distant planet, Pluto, has an orbital speed of 5 kilometers per second, and it requires 248 Earth-years to complete one revolution.

Imagine a planet's orbit drawn on a flat sheet of paper. The paper represents the planet's orbital plane. The orbital planes of seven planets lie within 3 degrees of the plane of the sun's equator. The other two, Mercury and Pluto, are inclined 7 and 17 degrees, respectively.

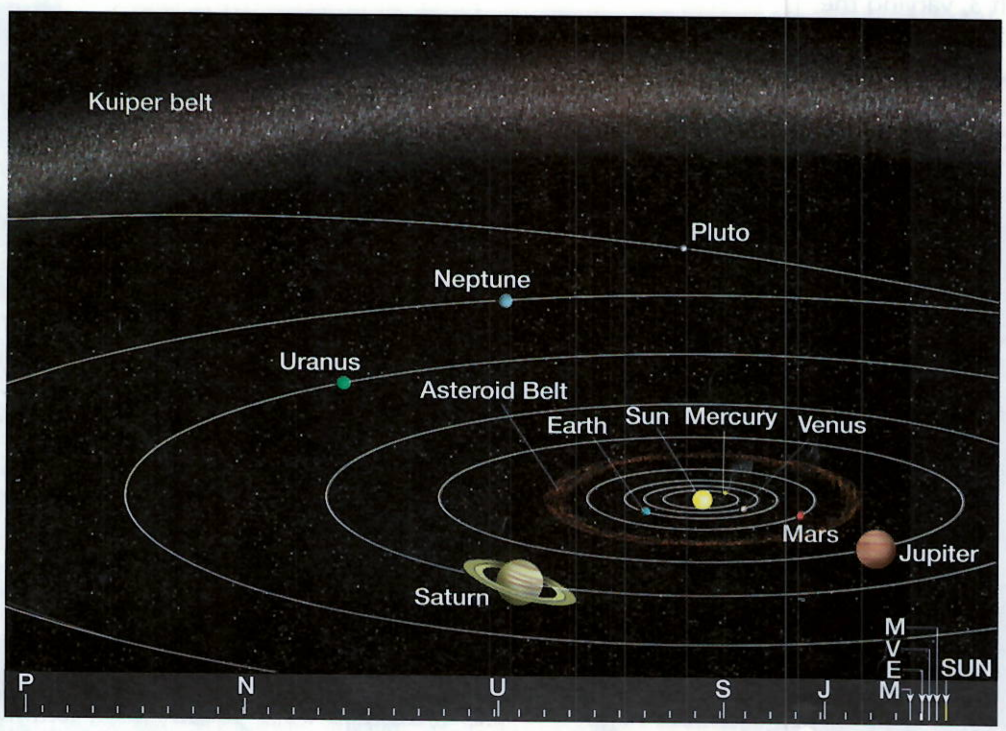


Figure 1 Orbits of the Planets The positions of the planets are shown to scale along the bottom of the diagram.

The Planets: An Overview

Careful examination of Table 1 shows that the planets fall quite nicely into two groups. The **terrestrial planets**—Mercury, Venus, Earth, and Mars—are relatively small and rocky. (*Terrestrial* = Earth-like.) The **Jovian planets**—Jupiter, Saturn, Uranus, and Neptune—are huge gas giants. (*Jovian* = Jupiter-like.) Small, cold Pluto does not fit neatly into either category.

Size is the most obvious difference between the terrestrial and the Jovian planets. The diameter of the largest terrestrial planet, Earth, is only one-quarter the diameter of the smallest Jovian planet, Neptune. Also, Earth's mass is only 1/17 as great as Neptune's. Hence, the Jovian planets are often called giants. Because of their distant locations from the sun, the four Jovian planets and Pluto are also called the outer planets. The terrestrial planets are closer to the sun and are called the inner planets. As we shall see, there appears to be a correlation between the positions of these planets and their sizes.

Density, chemical makeup, and rate of rotation are other ways in which the two groups of planets differ. The densities of the terrestrial planets average about five times the density of water. The Jovian planets, however, have densities that average only 1.5 times the density of water. One of the outer planets, Saturn, has a density only 0.7 times that of water, which means that Saturn would float if placed in a large enough water tank. The different chemical compositions of the planets are largely responsible for these density differences.

Reading Checkpoint *Compare the densities of terrestrial planets and Jovian planets.*

Table 1 Planetary Data

Planet	Average Distance from Sun: AU	Average Distance from Sun: Millions of km	Period of Revolution	Orbital Velocity km/s	Period of Rotation	Diameter (km)	Relative Mass (Earth = 1)	Average Density (g/cm^3)	Number of Known Satellites*
Mercury	0.39	58	88^d	47.5	59^d	4878	0.06	5.4	0
Venus	0.72	108	225^d	35.0	244^d	12,104	0.82	5.2	0
Earth	1.00	150	365.25^d	29.8	$23^h\ 56^m\ 04^s$	12,756	1.00	5.5	1
Mars	1.52	228	687^d	24.1	$24^h\ 37^m\ 23^s$	6794	0.11	3.9	2
Jupiter	5.20	778	12^{yr}	13.1	$9^h\ 50^m$	143,884	317.87	1.3	63
Saturn	9.54	1427	29.5^{yr}	9.6	$10^h\ 14^m$	120,536	95.14	0.7	31
Uranus	19.18	2870	84^{yr}	6.8	$17^h\ 14^m$	51,118	14.56	1.2	25
Neptune	30.06	4497	165^{yr}	5.3	$16^h\ 03^m$	50,530	17.21	1.7	13
Pluto	39.44	5900	248^{yr}	4.7	6.4^d	approx. 2300	0.002	1.8	1

*Includes all satellites discovered as of March 2004.

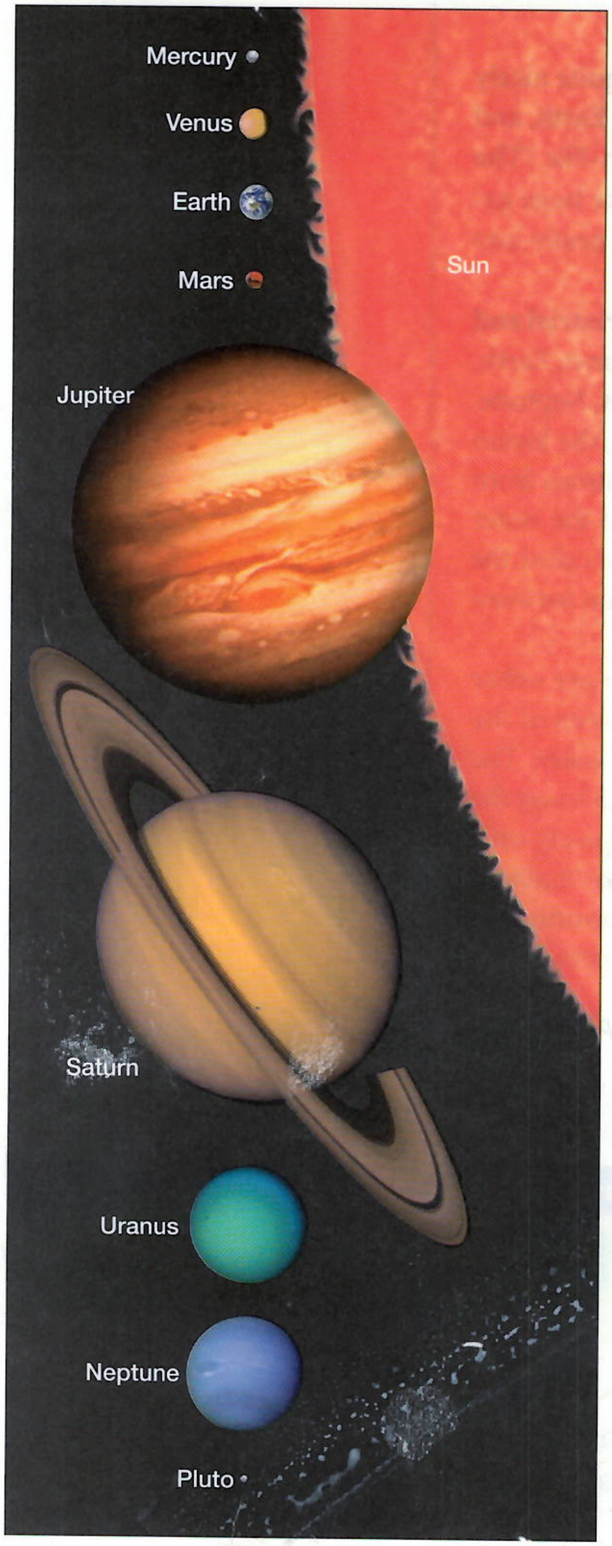


Figure 2 The planets are drawn to scale.
Interpreting Diagrams ***How do the sizes of the terrestrial planets compare with the sizes of the Jovian planets?***

The Interiors of the Planets The planets are shown to scale in Figure 2. The substances that make up the planets are divided into three groups: gases, rocks, and ices. The classification of these substances is based on their melting points.

1. The gases—hydrogen and helium—are those with melting points near absolute zero (−273°C or 0 kelvin).
2. The rocks are mainly silicate minerals and metallic iron, which have melting points above 700°C.
3. The ices include ammonia (NH_3), methane (CH_4), carbon dioxide (CO_2), and water (H_2O). They have intermediate melting points. For example, H_2O has a melting point of 0°C.

The terrestrial planets are dense, consisting mostly of rocky and metallic substances, and only minor amounts of gases and ices. The Jovian planets, on the other hand, contain large amounts of gases (hydrogen and helium) and ices (mostly water, ammonia, and methane). This accounts for their low densities. The outer planets also contain substantial amounts of rocky and metallic materials, which are concentrated in their cores.

The Atmospheres of the Planets The Jovian planets have very thick atmospheres of hydrogen, helium, methane, and ammonia. By contrast, the terrestrial planets, including Earth, have meager atmospheres at best. A planet's ability to retain an atmosphere depends on its mass and temperature, which accounts for the difference between Jovian and terrestrial planets.

Simply stated, a gas molecule can escape from a planet if it reaches a speed known as the escape velocity. For Earth, this velocity is 11 kilometers per second. Any material, including a rocket, must reach this speed before it can escape Earth's gravity and go into space.

A comparatively warm body with a small surface gravity, such as our moon, cannot hold even heavy gases, like carbon dioxide and radon. Thus, the moon lacks an atmosphere. The more massive terrestrial planets of Earth, Venus, and Mars retain some heavy gases. Still, their atmospheres make up only a very small portion of their total mass.

In contrast, the Jovian planets have much greater surface gravities. This gives them escape velocities of 21 to 60 kilometers per second—much higher than the terrestrial planets. Consequently, it is more difficult for gases to escape from their gravitational pulls. Also, because the molecular motion of a gas depends upon temperature, at the low temperatures of the Jovian planets even the lightest gases are unlikely to acquire the speed needed to escape.

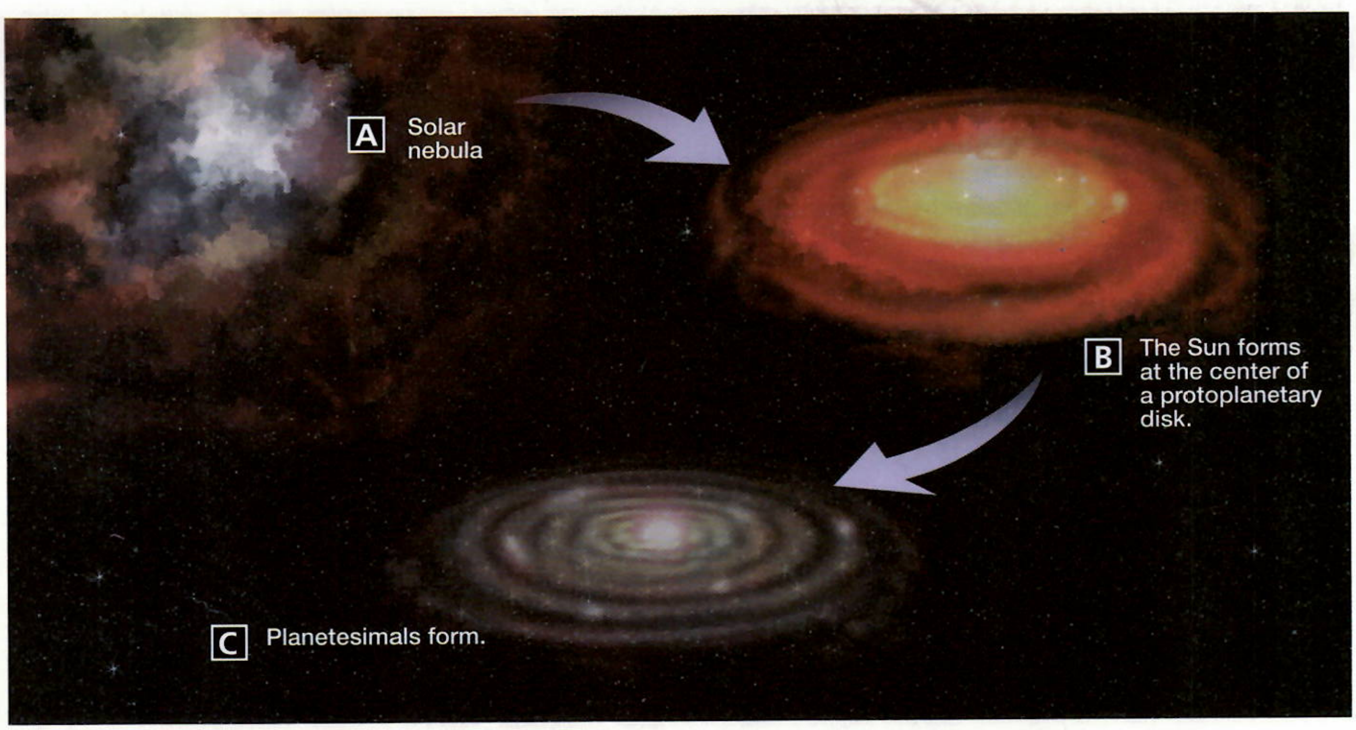
Formation of the Solar System

Between existing stars is "the vacuum of space." However, it is far from being a pure vacuum because it is populated with clouds of dust and gases. A cloud of dust and gas in space is called a **nebula** (*nebula* = cloud; plural: *nebulae*). A nebula, shown in Figure 3A, often consists of 92 percent hydrogen, 7 percent helium, and less than 1 percent of the remaining heavier elements. For some reason not yet fully understood, these thin gaseous clouds begin to rotate slowly and contract gravitationally. As the clouds contract, they spin faster. For an analogy, think of ice skaters—their speed increases as they bring their arms near their bodies.

Nebular Theory

Scientific studies of nebulae have led to a theory concerning the origin of our solar system. **According to the nebular theory, the sun and planets formed from a rotating disk of dust and gases.** As the speed of rotation increased, the center of the disk began to flatten out, as shown in Figure 3B. Matter became more concentrated in this center, where the sun eventually formed.

Figure 3 Formation of the Universe A According to the nebular theory, the solar system formed from a rotating cloud of dust and gas. **B** The sun formed at the center of the rotating disk. **C** Planetesimals collided, eventually gaining enough mass to be planets.



Planetesimals The growth of planets began as solid bits of matter began to collide and clump together through a process known as accretion. The colliding matter formed small, irregularly shaped bodies called **planetesimals.** As the collisions continued, the planetesimals grew larger, as shown in Figure 3C on page 647. They acquired enough mass to exert a gravitational pull on surrounding objects. In this way, they added still more mass and grew into true planets.

In the inner solar system, close to the sun, temperatures were so high that only metals and silicate minerals could form solid grains. It was too hot for ices of water, carbon dioxide, and methane to form. As shown in Figure 4, the inner planets grew mainly from substances with high melting points.

In the frigid outer reaches of the solar system, on the other hand, it was cold enough for ices of water and other substances to form. Consequently, the Jovian planets grew not only from accumulations of solid bits of material but also from large quantities of ices. Eventually, the Jovian planets became large enough to gravitationally capture even the lightest gases, such as hydrogen and helium. This enabled them to grow into giants.

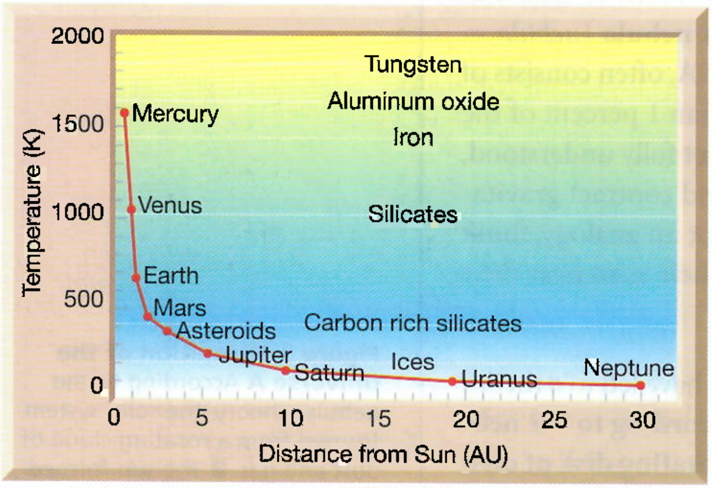


Figure 4 The terrestrial planets formed mainly from silicate minerals and metallic iron that have high melting points. The Jovian planets formed from large quantities of gases and ices.

Section 23.1 Assessment

Reviewing Concepts

1. Which planets are classified as terrestrial? Which planets are classified as Jovian?
2. Sequence the nine planets in order, beginning with the planet closest to the sun.
3. How do the terrestrial planets differ from the Jovian planets?
4. What is a nebula?
5. How did distance from the sun affect the size and composition of the planets?

Critical Thinking

6. **Summarizing** Summarize the nebular theory of the formation of the solar system.
7. **Inferring** Among the planets in our solar system, Earth is unique because water exists in all three states—solid, liquid, and gas—on its surface. How would Earth's water cycle be different if its orbit was outside the orbit of Mars?

Math Practice

8. Jupiter is 6.3×10^8 (630 million kilometers) from Earth. Calculate how long it would take to reach Jupiter if you traveled at
1) 100 km/h (freeway speed);
2) 1,000 km/h (jetliner speed);
3) 40,000 km/h (rocket speed); and
4) 3.0×10^8 km/s (speed of light).

23.2 The Terrestrial Planets

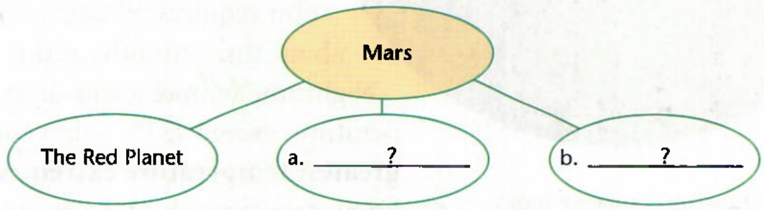
Reading Focus

Key Concepts

- What are the distinguishing characteristics of each terrestrial planet?

Reading Strategy

Using Prior Knowledge Copy the web diagram below. Before you read, add properties that you already know about Mars. Then add details about each property as you read. Make a similar web diagram for the other terrestrial planets.



In January 2004, the space rover, *Spirit*, bounced onto the rock-littered surface of Mars, known as the Red Planet. Shown in Figure 5, *Spirit* and its companion rover, *Opportunity*, were on the Red Planet to study minerals and geological processes, both past and present. They also searched for signs of the liquid water—such as eroded rocks or dry stream channels on Mars's surface. For the next few months, the rovers sent back to Earth numerous images and chemical analysis of Mars's surface. Much of what we learn about the planets has been gathered by rovers, such as *Spirit*, or space probes that travel to the far reaches of the solar system, such as *Voyager*. In this section, we'll explore three terrestrial planets—Mercury, Venus, and Mars—and see how they compare with the fourth terrestrial planet, Earth.

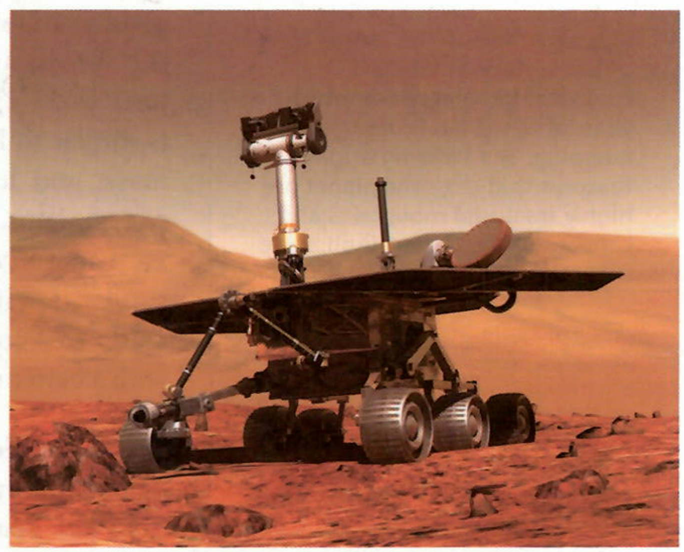


Figure 5 *Spirit* roved the surface of Mars and gathered data about the Red Planet's geologic past and present.

Mercury: The Innermost Planet

Mercury, the innermost and second smallest planet, is hardly larger than Earth's moon and is smaller than three other moons in the solar system. Like our own moon, it absorbs most of the sunlight that strikes it and reflects only 6 percent of sunlight back into space. This low percentage of reflection is characteristic of terrestrial bodies that have no atmosphere. Earth, on the other hand, reflects about 30 percent of the light that strikes it. Most of this reflection is from clouds.

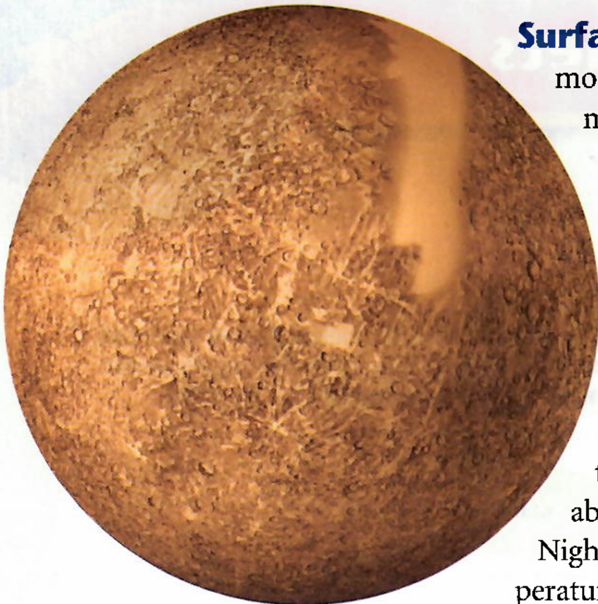


Figure 6 Mercury's surface looks somewhat similar to the far side of Earth's moon.

Surface Features Mercury has cratered highlands, much like the moon, and some smooth terrains that resemble maria. Unlike the moon, however, Mercury is a very dense planet, which implies that it contains a large iron core for its size. Also, Mercury has very long scarps (deep slopes) that cut across the plains and craters alike. These scarps may have resulted from crustal changes as the planet cooled and shrank.

Surface Temperature Mercury, shown in Figure 6, revolves around the sun quickly, but it rotates slowly. One full day-night cycle on Earth takes 24 hours. On Mercury, one rotation requires 59 Earth-days. Thus, a night on Mercury lasts for about three months and is followed by three months of daylight. Nighttime temperatures drop as low as –173°C, and noontime temperatures exceed 427°C—hot enough to melt lead. **Mercury has the greatest temperature extremes of any planet.** The odds of life as we know it existing on Mercury are almost nonexistent.

Reading Checkpoint *How does Mercury's period of rotation compare with Earth's?*

Venus: The Veiled Planet

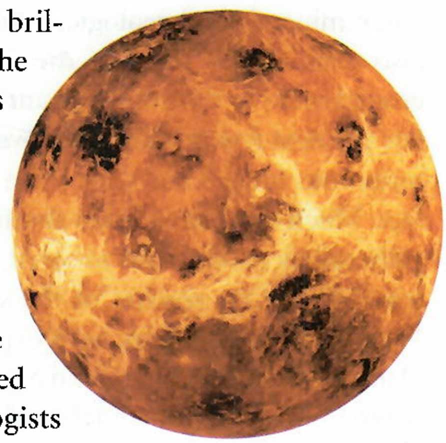


Figure 7 Venus This global view of the surface of Venus is computer generated from two years of Magellan Project radar mapping. The twisting bright features that cross the planet are highly fractured mountains and canyons of the eastern Aphrodite highland.

Venus, second only to the moon in brilliance in the night sky, is named for the goddess of love and beauty. It orbits the sun in a nearly perfect circle once every 255 Earth-days. Venus is similar to Earth in size, density, mass, and location in the solar system. Thus, it has been referred to as "Earth's twin." Because of these similarities, it is hoped that a detailed study of Venus will provide geologists with a better understanding of Earth's history.

Surface Features Venus is covered in thick clouds that visible light cannot penetrate. Nevertheless, radar mapping by the uncrewed *Magellan* spacecraft and by instruments on Earth have revealed a varied topography with features somewhat between those of Earth and Mars, as shown in Figure 7. To map Venus, radar pulses are sent toward the planet's surface, and the heights of plateaus and mountains are measured by timing the return of the radar echo. **These data have confirmed that basaltic volcanism and tectonic activity shape Venus's surface. Based on the low density of impact craters, these forces must have been very active during the recent geologic past.**

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About 80 percent of Venus's surface consists of plains covered by volcanic flows. Some lava channels extend hundreds of kilometers—one is 6800 kilometers long. Scientists have identified thousands of volcanic structures. Most are small shield volcanoes, although more than 1500 volcanoes greater than 20 kilometers across have been mapped. Figure 8 shows two of these volcanoes—one is Sapas Mons, 400 kilometers across and 1.5 kilometers high. Flows from this volcano mostly erupted from its flanks rather than its summit, in the manner of Hawaiian shield volcanoes.

Only 8 percent of Venus's surface consists of highlands that may be similar to continental areas on Earth. Tectonic activity on Venus seems to be driven by upwelling and downwelling of material in the planet's interior.

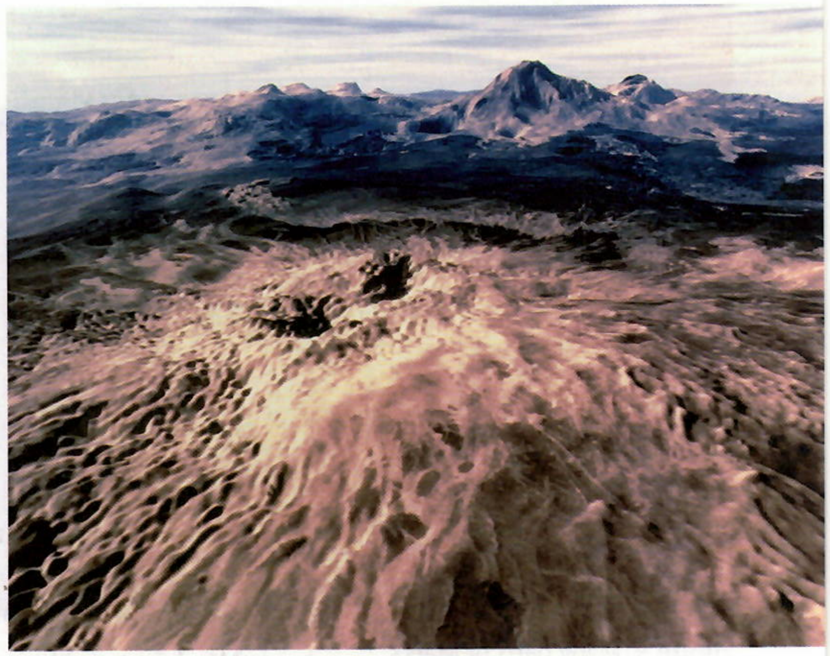


Figure 8 Sapas Mons and Maat Mons In this computer-generated image from Venus, Maat Mons, a large volcano, is near the horizon. Sapas Mons is the bright feature in the foreground.
Comparing and Contrasting ***What features on Venus are similar to those on Earth? What features are different?***

Surface Temperature Before the advent of spacecraft, Venus was considered to be a possible habitat for living things. However, evidence from space probes indicates otherwise. The surface temperature of Venus reaches 475°C, and its atmosphere is 97 percent carbon dioxide. Only small amounts of water vapor and nitrogen have been detected. Venus's atmosphere contains a cloud layer about 25 kilometers thick. The atmospheric pressure is 90 times that at Earth's surface. This hostile environment makes it unlikely that life as we know it exists on Venus.

Reading Checkpoint ***Describe the composition of Venus's atmosphere.***

Mars: The Red Planet

Mars has evoked greater interest than any other planet. When one imagines intelligent life on other worlds, little green Martians may come to mind. Mars is easy to observe, which may explain why so many people are fascinated by it. The surfaces of all other planets within telescopic range are hidden by clouds—except for Mercury, whose nearness to the sun makes viewing it difficult. Mars is known as the Red Planet because it appears as a reddish ball when viewed through a telescope. Mars also has some dark regions that change intensity during the Martian year. The most prominent telescopic features of Mars are its brilliant white polar caps.

The Martian Atmosphere

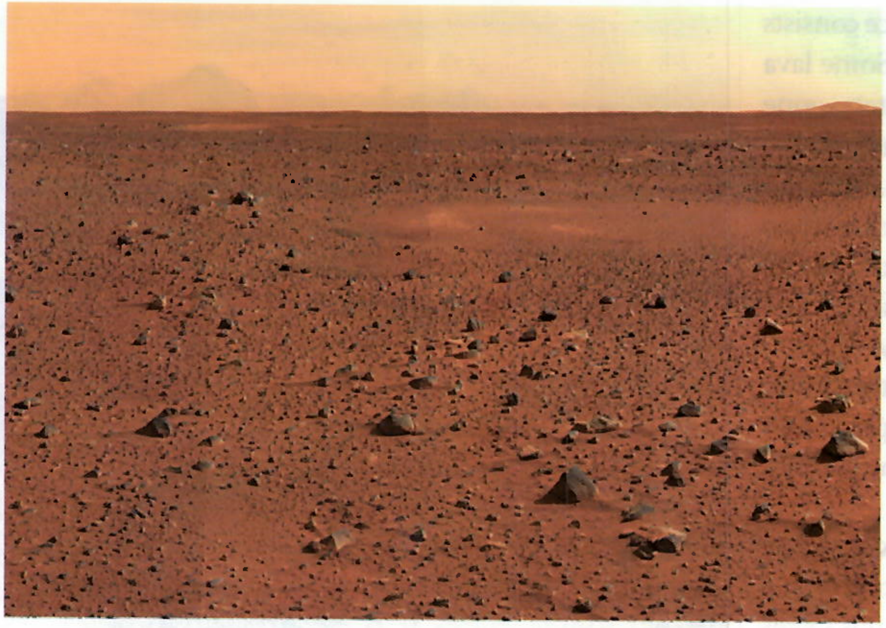


Figure 9 Many parts of Mars's landscape resemble desert areas on Earth.

The Martian atmosphere has only 1 percent the density of Earth's. It is made up primarily of carbon dioxide with tiny amounts of water vapor. Data from Mars probes confirm that the polar caps of Mars are made of water ice, covered by a thin layer of frozen carbon dioxide. As winter nears in either hemisphere, temperatures drop to −125°C, and additional carbon dioxide is deposited.

Although the atmosphere of Mars is very thin, extensive dust storms occur and may cause the color changes observed from Earth. Hurricane-force winds up to 270 kilometers per hour can persist for weeks. As shown in Figure 9, images from *Spirit* reveal a Martian landscape remarkably similar to a rocky desert on Earth, with abundant sand dunes and impact craters partially filled with dust.

Surface Features *Mariner 9*, the first spacecraft to orbit another planet, reached Mars in 1971 amid a raging dust storm. When the dust cleared, images of Mars' northern hemisphere revealed numerous large volcanoes. The biggest, Olympus Mons, is the size of Ohio and is 23 kilometers high—over two and a half times higher than Mount Everest. This gigantic volcano and others resemble Hawaiian shield volcanoes on Earth.

Most Martian surface features are old by Earth standards. The highly cratered southern hemisphere is probably 3.5 billion to 4.5 billion years old. Even the relatively "fresh" volcanic features of the northern hemisphere may be older than 1 billion years.

Another surprising find made by *Mariner 9* was the existence of several canyons that are much larger than Earth's Grand Canyon. The largest, Valles Marineris, is shown in Figure 10. It is thought to have formed by slippage of material along huge faults in the crustal layer. In this respect, it would be comparable to the rift valleys of Africa.

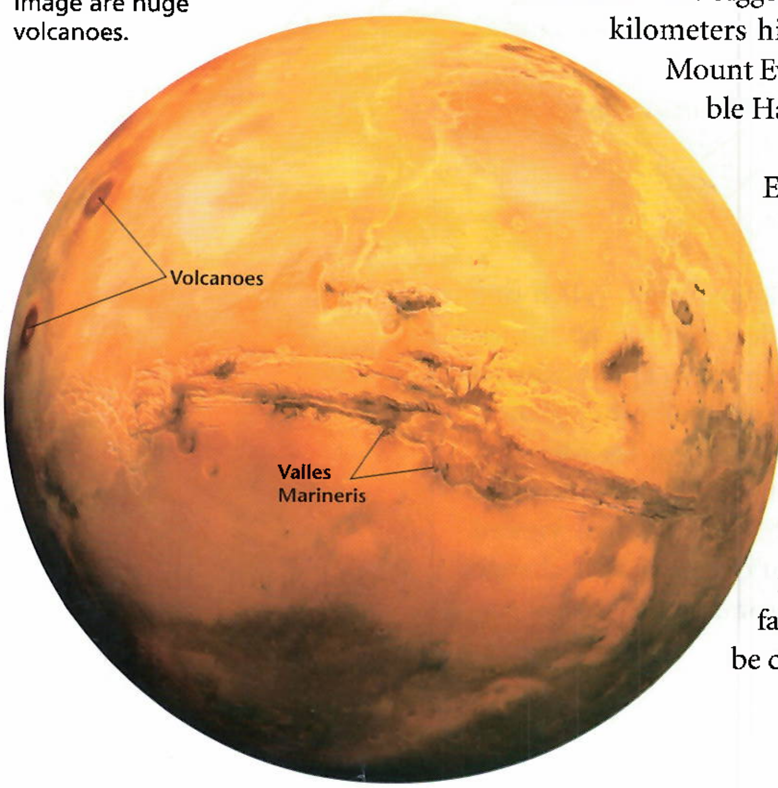


Figure 10 Valles Marineris Mars's Valles Marineris canyon system is more than 5000 kilometers long and up to 8 kilometers deep. The dark spots on the left edge of the image are huge volcanoes.

Water on Mars Some areas of Mars exhibit drainage patterns similar to those created by streams on Earth. The rover *Opportunity,* for example, found evidence of evaporite minerals and geologic formations associated with liquid water, as shown in Figure 11. In addition, *Viking* images have revealed ancient islands in what is now a dry streambed. When these streamlike channels were first discovered, some observers speculated that a thick water-laden atmosphere capable of generating torrential downpours once existed on Mars. If so, what happened to this water? The present Martian atmosphere contains only traces of water.

Images from the *Mars Global Surveyor* indicate that groundwater has recently migrated to the surface. These spring-like seeps have created gullies where they emerge from valley and crater walls. Some of the escaping water may have initially frozen due to the average Martian temperatures that range between −70°C and −100°C. Eventually, however, it seeped out as a slurry of sediment, ice, and liquid that formed the gullies.

Many scientists do not accept the theory that Mars once had an active water cycle similar to Earth's. Rather, they believe that most of the large stream-like valleys were created by the collapse of surface material caused by the slow melting of subsurface ice. Data from *Opportunity,* however, indicate that some areas were "drenched" in water. It will take scientists many months, if not years, to analyze the data gathered by the latest Mars mission. Because water is an essential ingredient for life, scientists and nonscientists alike are enthusiastic about exploring this phenomenon.

Figure 11 The composition and markings of some Martian rocks indicate that liquid water was once present on Mars's surface. The marking shown in the center of the rock, however, was created by a NASA rover during chemical analysis.

Section 23.2 Assessment

Reviewing Concepts

1. Which inner planet is smallest?
2. How does Venus compare with Earth?
3. Identify one distinguishing characteristic of each inner planet.
4. What surface features does Mars have that are also common on Earth?

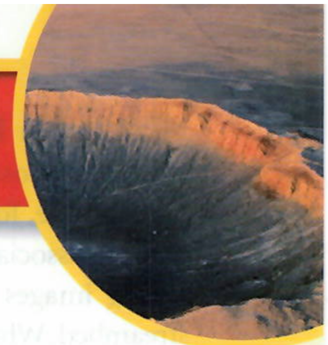
Critical Thinking

5. **Making Judgments** Besides Earth, which inner planet may have been most able to support life? Explain your answer.
6. **Relating Cause and Effect** Why are surface temperatures so high on Venus?

Writing in Science

Editorial A space mission to the moon or Mars often costs millions of dollars. Yet, it is hoped that space exploration can give us valuable knowledge about the solar system. Consider the pros and cons of space exploration. Then write an editorial stating whether or not you believe the costs are worth the potential benefits.

23.3 The Outer Planets



Reading Focus

Key Concepts

What characteristics distinguish each outer planet?

Reading Strategy

Summarizing Make a table like the one on the right that includes a row for each outer planet. Write a brief summary of the characteristics of each planet.

Outer Planets	Characteristics
Jupiter	largest; most mass, Great Red Spot
a. ___?___	b. ___?___
c. ___?___	d. ___?___

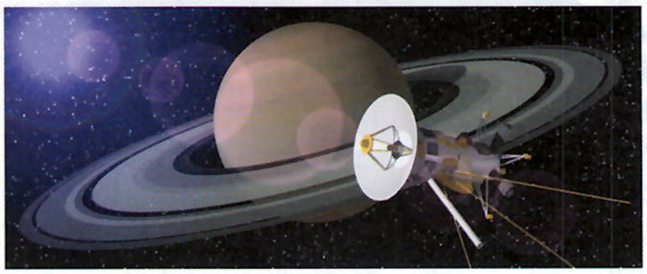


Figure 12 This artist's rendition shows *Cassini* approaching Saturn.

In 2004, the space probe *Cassini*, launched seven years earlier, finally reached the planet Saturn. The mission of *Cassini*, shown in Figure 12, is to explore Saturn's stunning ring system and its moons, including the unique moon Titan. During its four-year tour, *Cassini* is expected to orbit the ringed giant 74 times and make nearly four dozen flybys of Titan. The *Huygens* probe, carried into space by the *Cassini* orbiter, will descend to Titan's surface for further studies. In this section, we'll take a cue from *Cassini* and explore the outer planets—Jupiter, Saturn, Neptune, Uranus, and Pluto.

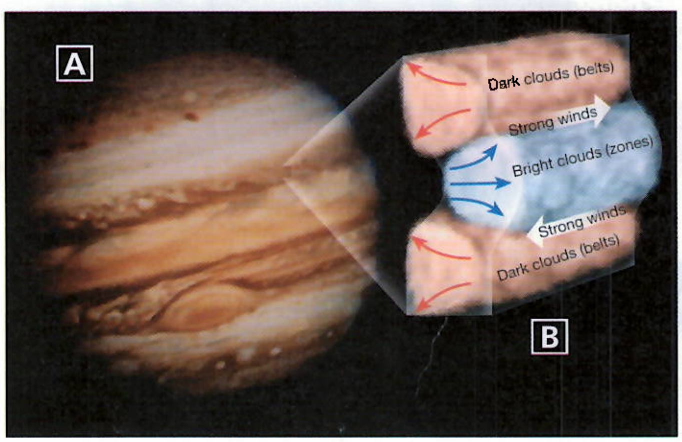


Figure 13 A When photographed by *Voyager 2*, the Great Red Spot was the size of two Earth-size circles placed side by side. **B** The light clouds are regions where gases are sinking and cooling. The convection currents and the rapid rotation of the planet generate high-speed winds.

Jupiter: Giant Among Planets

Jupiter is only 1/800 as massive as the sun. Still, it is the largest planet by far. **Jupiter has a mass that is 2 1/2 times greater than the mass of all the other planets and moons combined.** In fact, had Jupiter been about 10 times larger, it would have evolved into a small star. Jupiter rotates more rapidly than any other planet, completing one rotation in slightly less than 10 Earth-hours. The effect of this fast spin is to make its equatorial region bulge and its poles flatten slightly.

When viewed through a telescope or binoculars, Jupiter appears to be covered with alternating bands of multicolored clouds that run parallel to its equator. The most striking feature is the Great Red Spot in the southern hemisphere, shown in Figure 13A. The Great Red Spot was first discovered more than three centuries ago. However, when *Pioneer 11* moved within 42,000 kilometers of Jupiter's cloud tops, images from the orbiter indicated that the Great Red Spot is a cyclonic storm.

Structure of Jupiter Jupiter's hydrogen-helium atmosphere also contains small amounts of methane, ammonia, water, and sulfur compounds. The wind systems, shown in Figure 13B, generate the light- and dark-colored bands that encircle this giant. Unlike the winds on Earth, which are driven by solar energy, Jupiter itself gives off nearly twice as much heat as it receives from the sun. Thus, the interior heat from Jupiter produces huge convection currents in the atmosphere.

Atmospheric pressure at the top of the clouds is equal to sea-level pressure on Earth. Because of Jupiter's immense gravity, the pressure increases rapidly toward its surface. At 1000 kilometers below the clouds, the pressure is great enough to compress hydrogen gas into a liquid. Consequently, Jupiter is thought to be a gigantic ocean of liquid hydrogen. Less than halfway into Jupiter's interior, extreme pressures cause the liquid hydrogen to turn into liquid metallic hydrogen. Jupiter is also believed to have a rocky and metallic central core.

Jupiter's Moons Jupiter's satellite system, consisting of 28 moons discovered so far, resembles a miniature solar system. The four largest moons were discovered by Galileo. They travel in nearly circular orbits around the planet. To the surprise of almost everyone images from *Voyagers 1* and *2* in 1979 revealed that each of the four Galilean satellites is a unique geological world. The moons are shown in Figure 14. The innermost of the Galilean moons, Io, is one of three known volcanically active bodies in our solar system. The other volcanically active bodies are Earth—and Neptune's moon Triton. The heat source for volcanic activity on Io is thought to be tidal energy generated by a relentless "tug of war" between Jupiter and the other Galilean moons. The gravitational power of Jupiter and nearby moons pulls and pushes on Io's tidal bulge as its orbit takes it alternately closer to and farther from Jupiter. This gravitational flexing of Io is transformed into heat energy and results in Io's volcanic eruptions.

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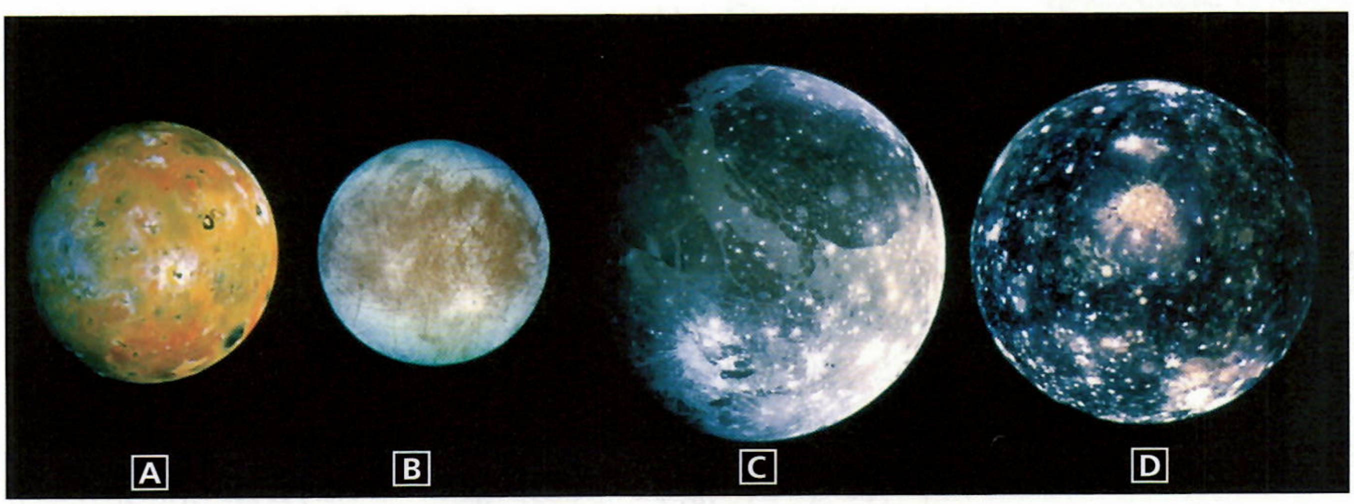


Figure 14 Jupiter's Moons
A Io is the innermost moon and is one of only three volcanically active bodies in the solar system. **B** Europa—the smallest of the Galilean moons—has an icy surface that is crossed by many linear features. **C** Ganymede is the largest Jovian moon, and it contains cratered areas, smooth regions, and areas covered by numerous parallel grooves. **D** Callisto—the outermost of the Galilean moons—is densely cratered, much like Earth's moon.

Jupiter's Rings Jupiter's ring system was one of the most unexpected discoveries made by *Voyager 1*. By analyzing how these rings scatter light, researchers concluded that the rings are composed of fine, dark particles, similar in size to smoke particles. The faint nature of the rings also indicates that these minute fragments are widely dispersed. The particles are thought to be fragments blasted by meteorite impacts from the surfaces of Metis and Adrastea, two small moons of Jupiter.

Reading Checkpoint ***Which Galilean moon is volcanically active?***

Saturn: The Elegant Planet

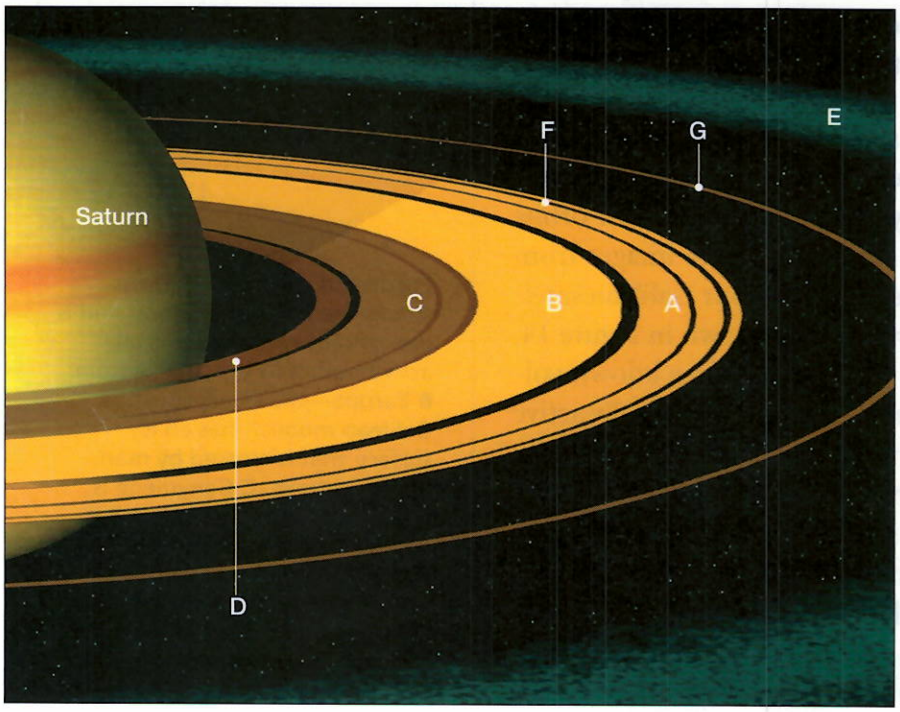


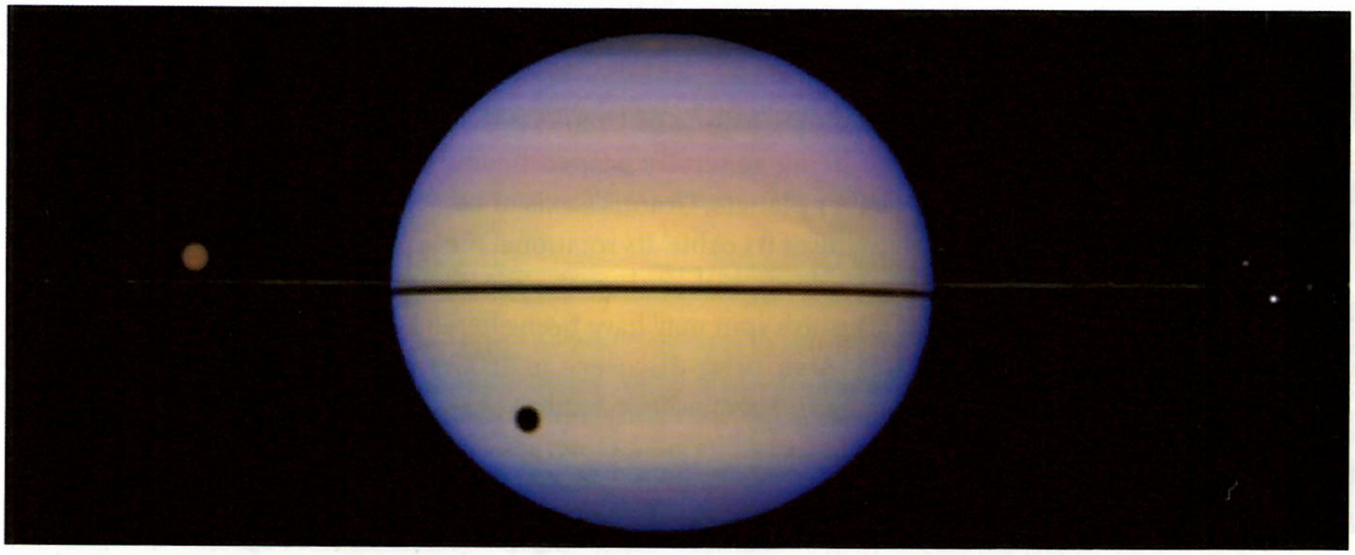
Figure 15 Saturn's Rings Saturn's rings fall into two categories based on particle density. The main rings (A and B) are densely packed. In contrast, the outer rings are composed of widely dispersed particles.

Requiring 29.46 Earth-years to make one revolution, Saturn is almost twice as far from the sun as Jupiter. However, its atmosphere, composition, and internal structure are thought to be remarkably similar to Jupiter's. **The most prominent feature of Saturn is its system of rings, shown in Figure 15.** In 1610, Galileo used a primitive telescope and first saw the structures that were later found to be the rings. They appeared as two small bodies adjacent to the planet. Their ring nature was explained 50 years later by the Dutch astronomer Christian Huygens.

Features of Saturn In 1980 and 1981, flyby missions of the nuclear-powered *Voyagers 1* and *2* spacecraft came within 100,000 kilometers of Saturn. More information was gained in a few days than had been acquired since Galileo first viewed this elegant planet.

1. Saturn's atmosphere is very active, with winds roaring at up to 1500 kilometers per hour.
2. Large cyclonic "storms" similar to Jupiter's Great Red Spot, although smaller, occur in Saturn's atmosphere.
3. Eleven additional moons were discovered.
4. The rings of Saturn were found to be more complex than expected.

More recently, observations from ground-based telescopes, the Hubble Space Telescope, and *Cassini* have added to our knowledge of Saturn's ring and moon system. When the positions of Earth and Saturn allowed the rings to be viewed edge-on—thereby reducing the glare from the main rings—Saturn's faintest rings and satellites became visible.



Saturn's Rings Until the discovery that Jupiter, Uranus, and Neptune also have ring systems, this phenomenon was thought to be unique to Saturn. Although the four known ring systems differ in detail, they share many attributes. They all consist of multiple concentric rings separated by gaps of various widths. In addition, each ring is composed of individual particles—"moonlets" of ice and rock—that circle the planet while regularly impacting one another.

Most rings fall into one of two categories based on particle density. Saturn's main rings, designated A and B in Figure 15, and the bright rings of Uranus are tightly packed and contain "moonlets" that range in size from a few centimeters to several meters. These particles are thought to collide frequently as they orbit the parent planet. Despite the fact that Saturn's dense rings stretch across several hundred kilometers, they are very thin, perhaps less than 100 meters from top to bottom.

At the other extreme, the faintest rings, such as Jupiter's ring system and Saturn's outermost rings, are composed of very fine particles that are widely dispersed. Saturn's outermost rings are designated E in Figure 15. In addition to having very low particle densities, these rings tend to be thicker than Saturn's bright rings.

Saturn's Moons Saturn's satellite system consists of 31 moons, some of which are shown in Figure 16. Titan is the largest moon and is bigger than Mercury. It is the second-largest moon in the solar system. Titan and Neptune's Triton are the only moons in the solar system known to have substantial atmospheres. Because of its dense gaseous cover, the atmospheric pressure at Titan's surface is about 1.5 times that at Earth's surface. Another moon, Phoebe, exhibits retrograde motion. It, like other moons with retrograde orbits, is most likely a captured asteroid or large planetesimal left over from the formation of the planets.

Reading Checkpoint ***How many moons of Saturn have been discovered thus far?***

Figure 16 Saturn's Moons This image of Saturn shows several of its moons.

Figure 17 This image of Titania, one of Uranus's moons, was taken by *Voyager 2* from a distance of 1 million kilometers.

Uranus: The Sideways Planet

A unique feature of Uranus is that it rotates "on its side." **Instead of being generally perpendicular to the plane of its orbit like the other planets, Uranus's axis of rotation lies nearly parallel with the plane of its orbit.** Its rotational motion, therefore, has the appearance of rolling, rather than the top-like spinning of the other planets. Uranus's spin may have been altered by a giant impact.

A surprise discovery in 1977 revealed that Uranus has a ring system. This find occurred as Uranus passed in front of a distant star and blocked its view. Observers saw the star "wink" briefly both before and after Uranus passed by. Later studies indicate that Uranus has at least nine distinct ring belts.

Spectacular views from *Voyager 2,* such as seen in Figure 17, show the varied terrains of the five largest moons of Uranus. Some have long, deep canyons and linear scars, whereas others possess large, smooth areas on otherwise crater-riddled surfaces. Miranda, the innermost of the five largest moons, has a greater variety of landforms than any body yet examined in the solar system.

Reading Checkpoint ***What is unique about Uranus's axis of rotation?***

Figure 18 The Great Dark Spot of Neptune is visible in the center of the left of the image. Bright cirrus-like clouds that travel at high speeds around the planet are also visible.
Identifying ***What is the Great Dark Spot?***

Neptune: The Windy Planet

As shown in Figure 18, Neptune has a dynamic atmosphere, much like those of Jupiter and Saturn. **Winds exceeding 1000 kilometers per hour encircle Neptune, making it one of the windiest places in the solar system.** It also has an Earth-size blemish called the Great Dark Spot that is reminiscent of Jupiter's Great Red Spot. The Great Dark Spot is assumed to be a large rotating storm. About five years after the Great Dark Spot was discovered, it vanished, only to be replaced by another dark spot in the planet's northern hemisphere.

Perhaps most surprising are the white, cirrus-like clouds that occupy a layer about 50 kilometers above the main cloud deck. The clouds are most likely frozen methane. Neptune has 13 known moons. *Voyager* images revealed that the bluish planet also has a ring system.

Triton, Neptune's largest moon, is nearly the size of Earth's moon. Triton is the only large moon in the solar system that exhibits retrograde motion. This motion indicates that Triton formed independently of Neptune and was gravitationally captured.

Triton also has the lowest surface temperature yet measured on any body in the solar system at −200°C. Its atmosphere is mostly nitrogen with a little methane. Despite low surface temperatures, Triton displays volcanic-like activity.

Pluto: Planet X

Pluto lies on the fringe of the solar system, almost 40 times farther from the sun than Earth. It is 10,000 times too dim to be visible to the unaided eye. Because of its great distance and slow orbital speed, it takes Pluto 248 Earth-years to orbit the sun. Since its discovery in 1930, it has completed about one-fourth of a revolution. **Pluto's orbit is highly eccentric, causing it to occasionally travel inside the orbit of Neptune, where it resided from 1979 through February 1999.**

In 1978 the moon Charon was discovered orbiting Pluto. Because of its close proximity to the planet, the best ground-based images of Charon show it only as an elongated bulge. In 1990 the Hubble Space Telescope produced a clearer image of the two icy worlds, shown in Figure 19. Charon orbits Pluto once every 6.4 Earth-days at a distance 20 times closer to Pluto than our moon is to Earth.

Current data indicate that Pluto has a diameter of approximately 2300 kilometers, making it the smallest planet in the solar system. Charon is about 1300 kilometers across, exceptionally large in proportion to its parent.

The average temperature of Pluto is estimated at −210°C, which is cold enough to solidify most gases that might be present. Thus, Pluto might best be described as a dirty iceball of frozen gases with lesser amounts of rocky substances.

A growing number of astronomers assert that Pluto's small size and location within a swarm of similar icy objects means that it should be reclassified as a minor planet. Other astronomers insist that demoting Pluto to a minor planet would dishonor astronomical history and confuse the public.

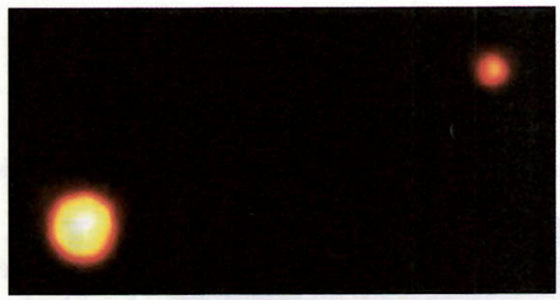


Figure 19 This Hubble image shows Pluto and its moon Charon.

Section 23.3 Assessment

Reviewing Concepts

1. What is the largest planet? What is the smallest?
2. What is Jupiter's Great Red Spot?
3. Identify one distinguishing characteristic of each outer planet.
4. How are Saturn's moon, Titan, and Neptune's Triton similar?
5. In what way is Io similar to Earth? What other body shows this similarity?

Critical Thinking

6. **Relating Cause and Effect** What may have caused Uranus's unique axis of rotation?
7. **Making Judgments** Should Pluto be reclassified as a minor planet? Explain your answer.

Connecting Concepts

Convection Currents Write a brief paragraph comparing and contrasting atmospheric convection currents on Jupiter and Earth.

23.4 Minor Members of the Solar System

Reading Focus

Key Concepts

- Where are most asteroids located?
- What is the structure of a comet?
- What is the origin of most meteoroids?

Vocabulary

- asteroid
- comet
- coma
- meteoroid
- meteor
- meteorite

Reading Strategy

Building Vocabulary Copy the table below. Then as you read the section, write a definition for each vocabulary term in your own words.

Vocabulary	Definition
asteroid	a. ?
b. ?	c. ?
d. ?	e. ?

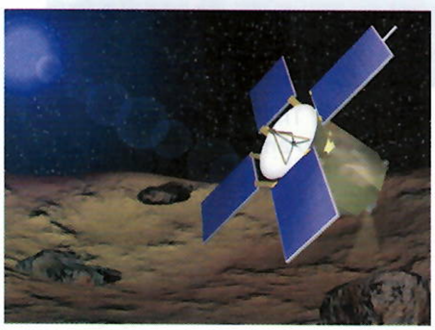


Figure 20 This artist's rendition shows *NEAR Shoemaker* touching down on the asteroid Eros.

In February 2001 an American spacecraft, *NEAR Shoemaker,* finished its mission in spectacular fashion—it became the first visitor to an asteroid. This historic accomplishment was not part of *NEAR Shoemaker's* original goal, which was to orbit the asteroid, taking images and gathering data about these objects in space. With this mission accomplished, however, NASA engineers wanted to see if they could actually land a spacecraft on an asteroid. The data they would gather would be priceless. As an added benefit, NASA would gain valuable experience that might help in the future to deflect an asteroid on a collision course with Earth.

Although it was not designed for landing, *NEAR Shoemaker*—shown in Figure 20—successfully touched down on the asteroid, Eros. It generated information that has planetary geologists both intrigued and perplexed. The spacecraft drifted toward the surface of Eros at the rate of 6 kilometers per hour. The images obtained revealed a barren, rocky surface composed of particles ranging in size from fine dust to boulders up to 8 meters across. Researchers unexpectedly discovered that fine debris is concentrated in the low areas that form flat deposits resembling ponds. Surrounding the low areas, the landscape is marked by an abundance of large boulders.

Seismic shaking is one of several hypotheses being considered as an explanation for the boulder-laden topography. This shaking would move the boulders upward. The larger materials rise to the top while the smaller materials settle to the bottom, which is similar to what happens when a can of mixed nuts is shaken.

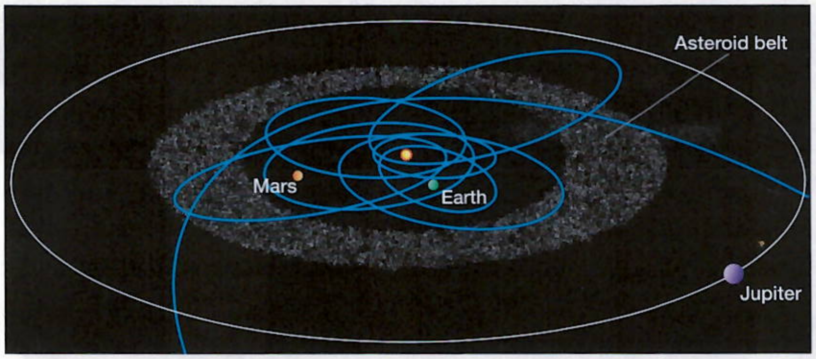


Figure 21 The orbits of most asteroids lie between Mars and Jupiter. Also shown are the orbits of a few near-Earth asteroids. Perhaps a thousand or more asteroids pass close to Earth. Luckily, only a few dozen are thought to be larger than 1 kilometer in diameter.

Asteroids: Microplanets

What exactly is an asteroid? **Asteroids** are small rocky bodies that have been likened to "flying mountains." The largest, Ceres, is about 1000 kilometers in diameter, but most are only about 1 kilometer across. The smallest asteroids are assumed to be no larger than grains of sand. **Most asteroids lie between the orbits of Mars and Jupiter. They have orbital periods of three to six years.** Some asteroids have very eccentric orbits and travel very near the sun, and a few larger ones regularly pass close to Earth and the moon as shown by the diagram in Figure 21. Many of the most recent impact craters on the moon and Earth were probably caused by collisions with asteroids. Inevitably, future Earth–asteroid collisions will occur, as discussed in this chapter's feature on page 665.

Many asteroids have irregular shapes, as shown in Figure 22. Because of this, planetary geologists first speculated that they might be fragments of a broken planet that once orbited between Mars and Jupiter. However, the total mass of the asteroids is estimated to be only 1/1000 that of Earth, which itself is not a large planet. What happened to the remainder of the original planet? Others have hypothesized that several larger bodies once coexisted in close proximity, and their collisions produced numerous smaller ones. The existence of several families of asteroids has been used to support this explanation. However, no conclusive evidence has been found for either hypothesis.

Figure 22 Asteroid 951, also called Gaspra, is probably the fragment of a larger body that was torn apart by a collision.

Reading Checkpoint ***What is an asteroid?***

Comets

Comets are among the most interesting and unpredictable bodies in the solar system. **Comets** are pieces of rocky and metallic materials held together by frozen gases, such as water, ammonia, methane, carbon dioxide, and carbon monoxide. Many comets travel in very elongated orbits that carry them far beyond Pluto. These comets take hundreds of thousands of years to complete a single orbit around the sun. However, a few have orbital periods of less than 200 years and make regular encounters with the inner solar system.

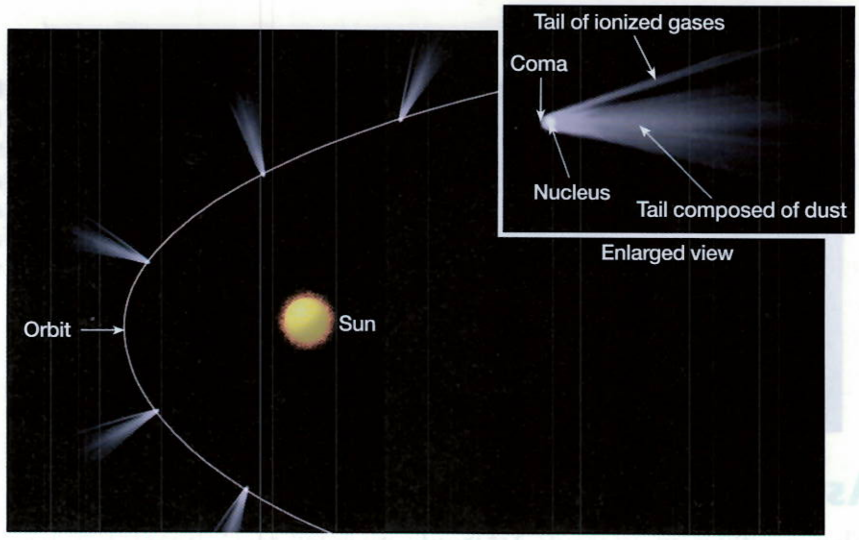


Figure 23 A comet's tail always points away from the sun.

Coma When first observed, a comet appears very small. But as it approaches the sun, solar energy begins to vaporize the frozen gases. This produces a glowing head called the **coma,** shown in Figure 23. **A small glowing nucleus with a diameter of only a few kilometers can sometimes be detected within a coma. As comets approach the sun, some, but not all, develop a tail that extends for millions of kilometers.**

The fact that the tail of a comet points away from the sun in a slightly curved manner led early astronomers to propose that the sun has a repulsive force that pushes the particles of the coma away, thus forming the tail. Today, two solar forces are known to contribute to this formation. One, radiation pressure, pushes dust particles away from the coma. The second, known as solar wind, is responsible for moving the ionized gases, particularly carbon monoxide. You'll learn more about solar wind in the next chapter. Sometimes a single tail composed of both dust and ionized gases is produced, but often two tails are observed.

As a comet moves away from the sun, the gases forming the coma recondense, the tail disappears, and the comet returns to cold storage. Material that was blown from the coma to form the tail is lost from the comet forever. Therefore it is believed that most comets cannot survive more than a few hundred close orbits of the sun. Once all the gases are expelled, the remaining material—a swarm of tiny metallic and stony particles—continues the orbit without a coma or a tail.

Kuiper Belt Comets apparently originate in two regions of the outer solar system. Those with short orbital periods are thought to orbit beyond Neptune in a region called the Kuiper belt. Like the asteroids in the inner solar system, most Kuiper belt comets move in nearly circular orbits that lie roughly in the same plane as the planets. A chance collision between two Kuiper belt comets, or the gravitational influence of one of the Jovian planets, may occasionally alter the orbit of a comet enough to send it to the inner solar system, and into our view.

Reading Checkpoint *In which direction does the tail of a comet point?*

Oort Cloud Unlike Kuiper belt comets, comets with long orbital periods aren't confined to the plane of the solar system. These comets appear to be distributed in all directions from the sun, forming a spherical shell around the solar system called the Oort cloud. See Figure 24. Millions of comets are believed to orbit the sun at distances greater than 100,000 times the Earth-sun distance. The gravitational effect of another object in space is thought to send an occasional Oort cloud comet into a highly eccentric orbit that carries it toward the sun. However, only a tiny portion of the Oort cloud comets pass into the inner solar system.

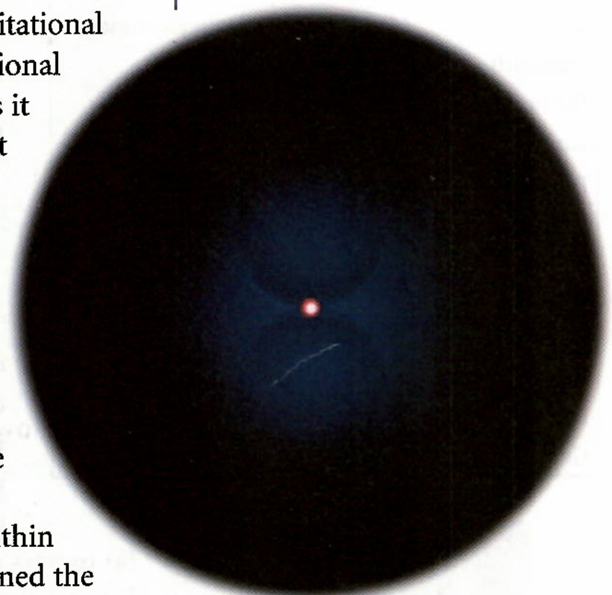


Figure 24 The Oort cloud is a sphere of comets surrounding the sun and planets.

Halley's Comet The most famous short-period comet is Halley's comet. Its orbital period averages 76 years, and every one of its 29 appearances since 240 B.C. has been recorded by Chinese astronomers. When seen in 1910, Halley's comet had developed a tail nearly 1.6 million kilometers long and was visible during the daylight hours.

In 1986, the European probe *Giotto* approached to within 600 kilometers of the nucleus of Halley's comet and obtained the first images of this elusive structure. We now know that the nucleus is potato-shaped, 16 kilometers by 8 kilometers. The surface is irregular and full of craterlike pits. Gases and dust that vaporize from the nucleus to form the coma and tail appear to gush from its surface as bright jets or streams. Only about 10 percent of the comet's total surface was emitting these jets at the time of the rendezvous. The remaining surface area of the comet appeared to be covered with a dark layer that may consist of organic material.

Meteoroids

Nearly everyone has seen a "shooting star." This streak of light occurs when a meteoroid enters Earth's atmosphere. A **meteoroid** is a small solid particle that travels through space. **Most meteoroids originate from any one of the following three sources: (1) interplanetary debris that was not gravitationally swept up by the planets during the formation of the solar system, (2) material from the asteroid belt, or (3) the solid remains of comets that once traveled near Earth's orbit.** A few meteoroids are believed to be fragments of the moon, or possibly Mars, that were ejected when an asteroid impacted these bodies.

Some meteoroids are as large as asteroids. Most, however, are the size of sand grains. Consequently, they vaporize before reaching Earth's surface. Those that do enter Earth's atmosphere and burn up are called **meteors.** The light that we see is caused by friction between the particle and the air, which produces heat.

Table 2 Major Meteor Showers

Shower	Approximate Dates	Associated Comet
Quadrantids	Jan. 4–6	
Lyrids	Apr. 20–23	Comet 1861 I
Eta Aquarids	May 3–5	Halley's comet
Delta Aquarids	July 30	
Perseids	Aug. 12	Comet 1862 III
Draconids	Oct. 7–10	Comet Giacobini-Zinner
Orionids	Oct. 20	Halley's comet
Taurids	Nov. 3–13	Comet Encke
Andromedids	Nov. 14	Comet Biela
Leonids	Nov. 18	Comet 1866 I
Geminids	Dec. 4–16	

Occasionally, meteor sightings can reach 60 or more per hour. These displays, called meteor showers, result when Earth encounters a swarm of meteoroids traveling in the same direction and at nearly the same speed as Earth. As shown in Table 2, the close association of these swarms to the orbits of some comets strongly suggests that they are material lost by these comets. The notable Perseid meteor shower occurs each year around August 12 and is believed to be the remains of the Comet 1862 III.

Reading Checkpoint *What is a meteor shower?*

Figure 25 This meteorite, made up of mostly iron, was found in the desert sands.

A meteoroid that actually reaches Earth's surface is called a **meteorite.** A few very large meteorites have blasted out craters on Earth's surface, similar to those on the moon. The most famous is Meteor Crater in Arizona. (See pages 642–643.) This huge cavity is about 1.2 kilometers across, 170 meters deep, and has an upturned rim that rises 50 meters above the surrounding countryside. Over 30 tons of iron fragments have been found in the immediate area, but attempts to locate the main body have been unsuccessful. Based on erosion, the impact likely occurred within the last 20,000 years.

Prior to moon rocks brought back by astronauts, meteorites such as the one in Figure 25 were the only extraterrestrial materials that could be directly examined. Meteorite dating indicates that our solar system's age exceeds 4.5 billion years. This "old age" has been confirmed by data from lunar samples.

Section 23.4 Assessment

Reviewing Concepts

1. Where are most asteroids located?
2. Describe the structure of a comet.
3. Where do short-period comets come from? What about long-period comets?
4. Meteoroids originate from what three sources?

Critical Thinking

5. **Comparing and Contrasting** Compare and contrast a meteoroid, meteor, and meteorite.
6. **Predicting** What do you think would happen if Earth passed through the tail of a comet?

Math Practice

7. It has been estimated that Halley's comet has a mass of 1×10^{11} tons. This comet is estimated to lose 1×10^{8} tons of material each time its orbit brings it close to the sun. With an orbital period of 76 years, what is the maximum remaining life span of Halley's comet?

Analyze and Conclude

1. **Using Models** Where is Earth located on your model? Where are the rest of the planets located?
2. **Observing** What pattern of spacing do you observe? Summarize the pattern for both the inner and outer planets.
3. **Interpreting Data** Which planet or planets vary most from the general pattern of spacing?

Go Further Determine how to expand your model to include the scale sizes of the planets. Refer to the table for the diameters of each planet (Table 3). Develop a scale, and then calculate the proper scale size of the planets. Draw the planets to scale on your model.

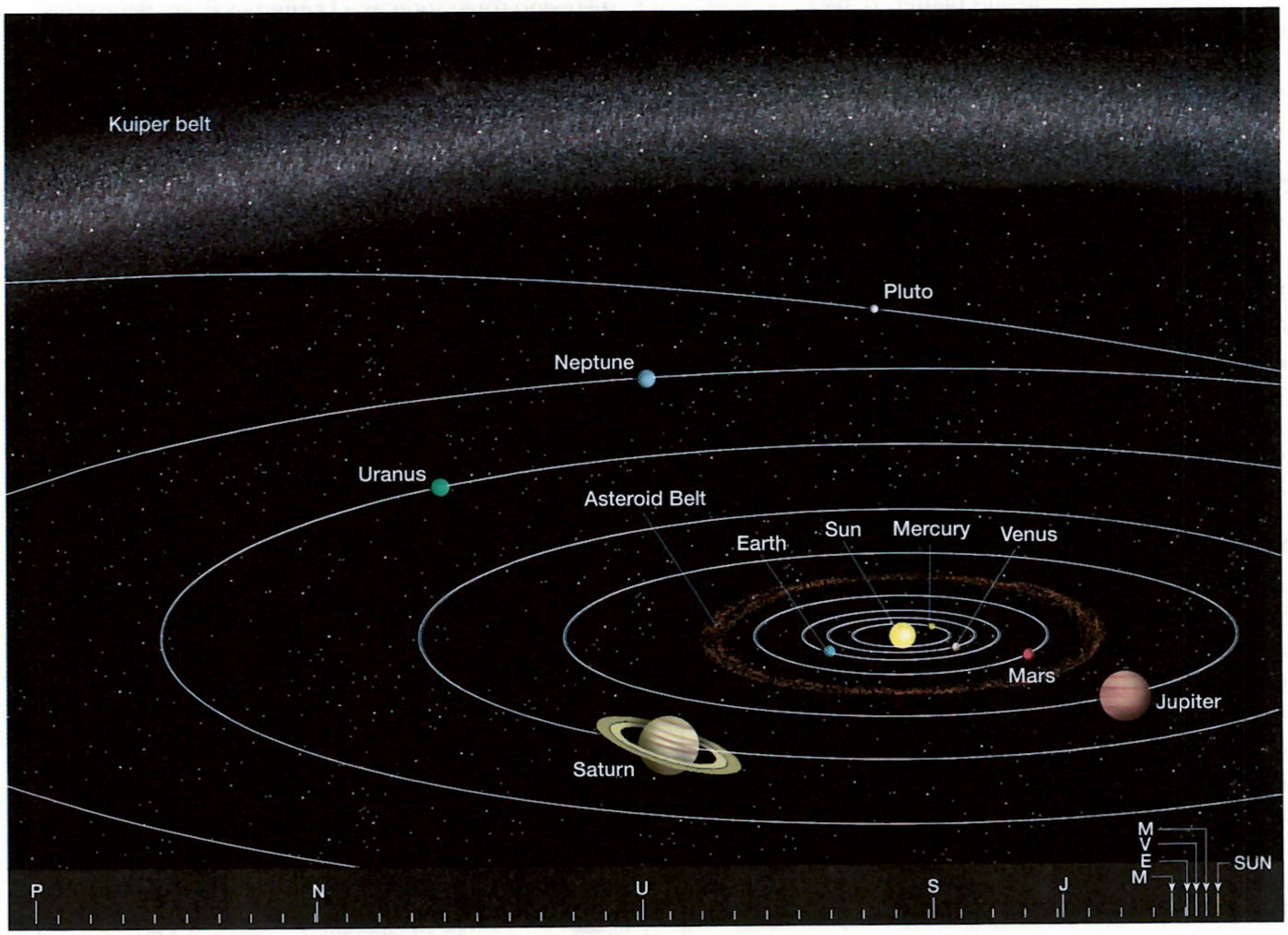


Figure A

CHAPTER 23

Study Guide

23.1 The Solar System

Key Concepts

- Size is the most obvious difference between the terrestrial and the Jovian planets.
- Density, chemical makeup, and rate of rotation are other ways in which the two groups of planets differ.
- According to the nebular theory, the sun and planets formed from a rotating disk of dust and gases.

Vocabulary

terrestrial planet, *p. 645;* Jovian planet, *p. 645;* nebula, *p. 647;* planetesimal, *p. 648*

23.2 The Terrestrial Planets

Key Concepts

- Mercury has the greatest temperature extremes of any planet.
- The surface temperature of Venus reaches 475°C, and its atmosphere is 97 percent carbon dioxide.
- Some areas of Mars exhibit drainage patterns similar to those created by streams on Earth.

23.3 The Outer Planets

Key Concepts

- Jupiter has a mass that is 2 1/2 times greater than the mass of all the other planets and moons combined.
- The most prominent feature of Saturn is its system of rings.
- Instead of being generally perpendicular to the plane of its orbit like the other planets, Uranus's axis of rotation lies nearly parallel with the plane of its orbit.
- Winds exceeding 1000 kilometers per hour encircle Neptune, making it one of the windiest places in the solar system.
- Pluto's orbit is highly eccentric, causing it to occasionally travel inside the orbit of Neptune, where it resided from 1979 through February 1999.

23.4 Minor Members of the Solar System

Key Concepts

- Most asteroids lie between the orbits of Mars and Jupiter. They have orbital periods of three to six years.
- A small glowing nucleus with a diameter of only a few kilometers can sometimes be detected within a coma. As comets approach the sun, some, but not all, develop a tail that extends for millions of kilometers.
- Most meteoroids originate from any one of the following three sources: (1) interplanetary debris that was not gravitationally swept up by the planets during the formation of the solar system, (2) material from the asteroid belt, or (3) the solid remains of comets that once traveled near Earth's orbit.

Vocabulary

asteroid, *p. 661;* comet, *p. 661;* coma, *p. 662;* meteoroid, *p. 663;* meteor, *p. 663;* meteorite, *p. 664*

Thinking Visually

Copy and complete the table below comparing and contrasting the inner and outer planets. Include information about each planet's diameter, distance from the sun, composition, and number of moons.

Inner and Outer Planets		
Inner Planets		
	Diameter	**Distance from Sun**
Mercury	4878 km	0.39 AU
a. ___?___		
b. ___?___		
c. ___?___		
Outer Planets		
	Diameter	**Distance from Sun**
Jupiter	143,884 km	5.3 AU
d. ___?___		
e. ___?___		
f. ___?___		
g. ___?___		

CHAPTER 23

Assessment

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Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Which of these planets is not a terrestrial planet?
   - a. Earth
   - b. Mercury
   - c. Venus
   - d. Uranus
2. What theory describes the formation of the solar system from a huge cloud of dust and gases?
   - a. protoplanet theory
   - b. nebular theory
   - c. planetesimal theory
   - d. solar theory
3. Which of the following is NOT a characteristic of Jovian planets?
   - a. large size
   - b. composed mostly of gases and ice
   - c. lack of moons
   - d. located beyond the orbit of Mars
4. Which planet was explored by the rovers *Spirit* and *Opportunity?*
   - a. Mercury
   - b. Pluto
   - c. Mars
   - d. Venus
5. Which two planets are most alike?
   - a. Jupiter and Pluto
   - b. Earth and Mercury
   - c. Mars and Uranus
   - d. Uranus and Saturn
6. Which of the following is NOT true of Jupiter?
   - a. It is more massive than all the other planets and moons combined.
   - b. It has huge rotating storms.
   - c. It has a thin ring system.
   - d. It has a solid surface.
7. Which moon is known to have active volcanism?
   - a. Io
   - b. Phobos
   - c. Europa
   - d. Titan
8. What bodies in the solar system orbit between Mars and Jupiter?
   - a. comets
   - b. stars
   - c. asteroids
   - d. meteorites
9. A comet's tail always points
   - a. away from the sun.
   - b. toward the sun.
   - c. up.
   - d. down.
10. Meteoroids that strike Earth are called
    - a. asteroids.
    - b. comets.
    - c. meteors.
    - d. meteorites.

Understanding Concepts

11. What objects are found in the solar system?
12. What substances make up most of the solar system? Classify them as gas, rock, or ice.
13. Describe general characteristics and location of the terrestrial planets.
14. What is Olympus Mons? Where is it found?
15. Why has Mars been the planet most studied by telescopes?
16. Why is life unlikely to exist on Venus?
17. Which planets have ring systems?
18. What three bodies in the solar system exhibit volcanic activity?
19. What are moonlets?
20. How are Uranus and Neptune similar?
21. Why isn't Pluto classified as either a terrestrial planet or a Jovian planet?
22. How big is the largest asteroid?
23. Which minor members of the solar system are thought to have formed beyond the orbit of Pluto?
24. What is the bright glowing head of a comet called?
25. What evidence indicates that our solar system is about 4.5 billion years old?

Assessment *continued*

Critical Thinking

26. **Analyzing Data** What evidence supports the theory that liquid water may have existed on Mars? What evidence refutes the possibility of a wet Martian climate?

27. **Drawing Conclusions** Mercury is closer to the sun than Venus. Venus, however, is hotter. Why?

28. **Inferring** What can you infer about a moon that exhibits retrograde motion?

29. **Making Generalizations** Why is it more difficult for gases to escape from the Jovian planets than from the terrestrial planets?

30. **Applying Concepts** Why would it be difficult to verify that an impact may have altered Uranus's axis of rotation?

Analyzing Data

Use the table in the right column to answer Questions 31–34.

31. **Identifying** Which two planets have similar atmospheric compositions?

32. **Interpreting Data** What makes these two planets' atmospheres very different?

33. **Inferring** What gas is present in Earth's atmosphere, but nearly absent in the atmospheres of Venus and Mars? What do you think explains its presence on Earth? (*Hint:* What does Earth have that Venus and Mars both lack?)

34. **Analyzing Data** Based on the data in the table, how would you describe the effect of increasing atmospheric pressure on surface temperature?

Concepts in Action

35. **Relating Cause and Effect** Weight is a function of the gravitational attraction of an object on your mass. On which planet would you weigh the least? Explain your answer.

36. **Calculating** Refer to Table 1 on page 645. Using the table, determine how old you are in Jupiter-years.

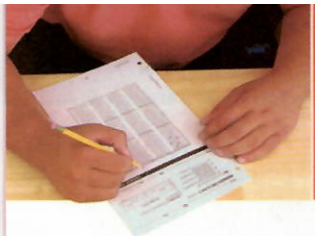
37. **Identifying** Which features on Earth offer clear evidence that comets and asteroids have struck its surface?

Performance-Based Assessment

Using Models Use a fan, a Styrofoam ball, several pushpins, and several pieces of ribbon to create a model of a comet. Explain what each part of the model represents. Work with a partner to demonstrate the orbit of your model. Make sure that the "tail" points in the proper direction.

Comparison of the Atmospheres and Surface Temperatures of Mercury, Venus, Earth, Mars

Planet or Body	Gases (% by volume)			Surface Temperature (range)	Surface Atmospheric Pressure (bars)
	N_2	O_2	CO_2		
Mercury	0	trace	0	−173° to 427°C	10^{-15}
Venus	3.5	< 0.01	96.5	475°C (small range)	92
Earth	78.01	20.95	0.03	−40° to 75°C	1.014
Mars	2.7	1.3	95.32	−120° to 25°C	0.008



Standardized Test Prep

Test-Taking Tip

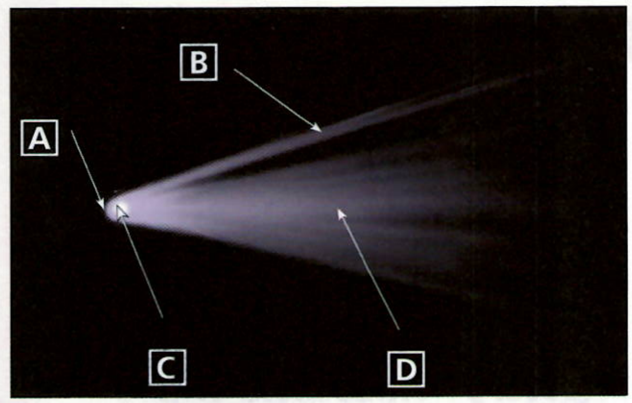
Questions with NOT
Questions containing absolute negative qualifiers, such as NOT, can be tricky. If the question lists statements, it helps to look at each statement and add NOT just before the verb. For example, rephrase statement A below as "Mars does NOT have moons." Then try to think of one example that disproves this statement. Mars and Earth are the only two terrestrial planets that have moons. Thus, the statement is not true. Repeat this process for each choice until you find one that is true in all cases.

Which of the following is NOT true of Mars?
(A) Mars has moons.
(B) Mars has rings.
(C) Mars is often called the Red Planet.
(D) Mars has volcanoes.

(Answer: B)

1. Which is NOT the most obvious difference between the terrestrial and Jovian planets?
   (A) mass
   (B) color
   (C) density
   (D) chemical makeup
2. Which planet does NOT have a density that is greater than water?
   (A) Mercury
   (B) Pluto
   (C) Venus
   (D) Saturn
3. Why was Mercury unable to retain an atmosphere during its formation?
   (A) Mercury has a high surface temperature and has a low mass.
   (B) Mercury is the largest planet.
   (C) Mercury is the farthest planet from the sun.
   (D) Mercury revolves slowly.
4. What causes the bright streak in the sky known as a meteor?

Use the photograph below to answer Questions 5 and 6.



5. What features do labels B and D represent? What forces produce these features?
6. What are features A and C? How do they differ?