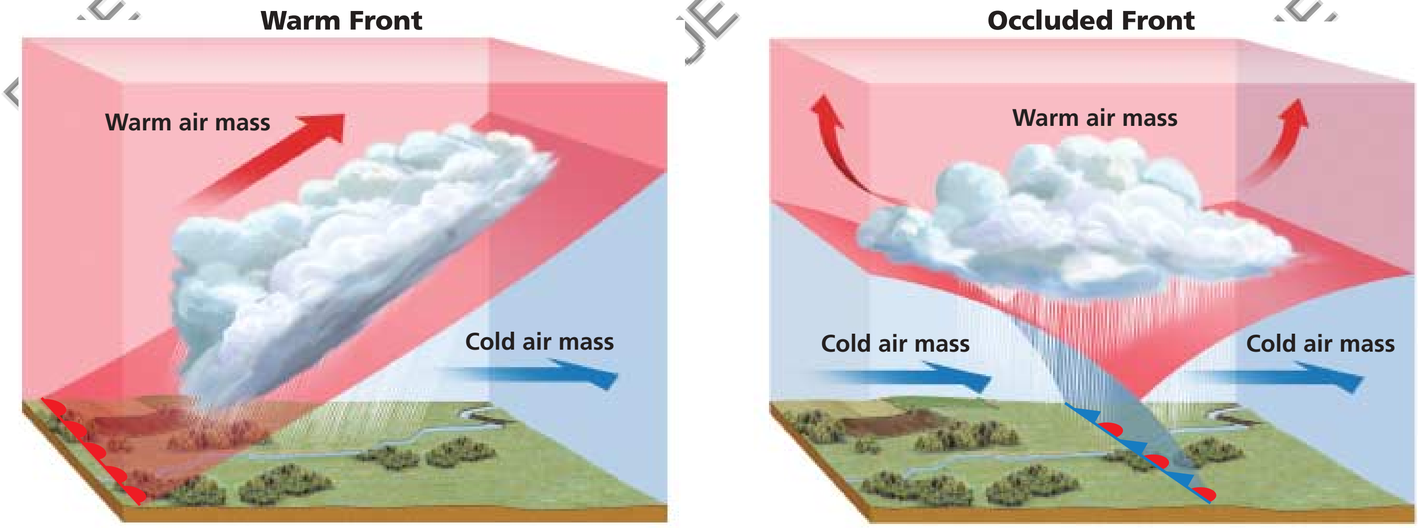

Figure 2 ▶ As a warm air mass rises over a cold air mass (left), a warm front forms at the boundary of the two air masses. An occluded front (right) forms when a cold air mass lifts a warm air mass off the ground.

warm front the front edge of advancing warm air mass that replaces colder air with warmer air

stationary front a front of air masses that moves either very slowly or not at all

occluded front a front that forms when a cold air mass overtakes a warm air mass and lifts the warm air mass off the ground and over another air mass

midlatitude cyclone an area of low pressure that is characterized by rotating wind that moves toward the rising air of the central low-pressure region

Warm Fronts

When a cold air mass retreats from an area, a **warm front** forms. The less dense warm air rises over the cooler air. The slope of a warm front is gradual, as shown in **Figure 2.** Because of this gentle slope, clouds may extend far ahead of the surface location, or *base,* of the front. A warm front generally produces precipitation over a large area and may cause violent weather.

Stationary and Occluded Fronts

Sometimes, when two air masses meet, the cold air moves parallel to the front, and neither air mass is displaced. A front at which air masses move either very slowly or not at all is called a **stationary front.** The weather around a stationary front is similar to that produced by a warm front. An **occluded front** usually forms when a fast-moving cold front overtakes a warm front and lifts the warm air off the ground completely, as shown in **Figure 2.**

Polar Fronts and Midlatitudes Cyclones

Over each of Earth's polar regions is a dome of cold air that may extend as far as 60° latitude. The boundary where this cold polar air meets the tropical air mass of the middle latitudes, especially over the ocean, is called the *polar front*. Waves commonly develop along the polar front. A *wave* is a bend that forms in a cold front or a stationary front. This wave is similar to the waves that moving air produces when it passes over a body of water. However, waves that form in a cold front or stationary front are much larger. They are the beginnings of low-pressure storm centers called midlatitude cyclones or *wave cyclones*. **Midlatitude cyclones** are areas of low pressure that are characterized by rotating wind that moves toward the rising air of the central, low-pressure region. These cyclones strongly influence weather patterns in the middle latitudes.

Stages of a Midlatitude Cyclone

A midlatitude cyclone usually lasts several days. The stages of formation and dissipation of a midlatitude cyclone are shown in **Figure 3.** In North America, midlatitude cyclones generally travel about 45 km/h in an easterly direction as they spin counterclockwise. They follow several storm tracks, or routes, as they move from the Pacific coast to the Atlantic coast. As they pass over the western mountains, they may lose their moisture and energy.

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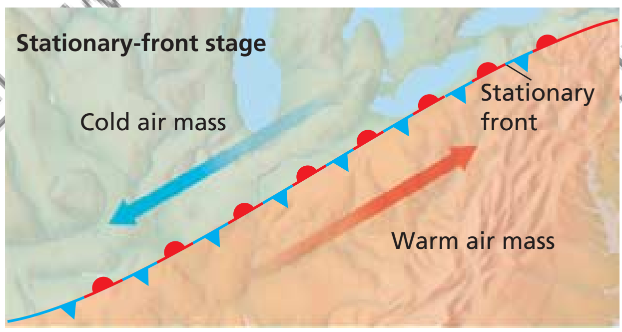
Anticyclones

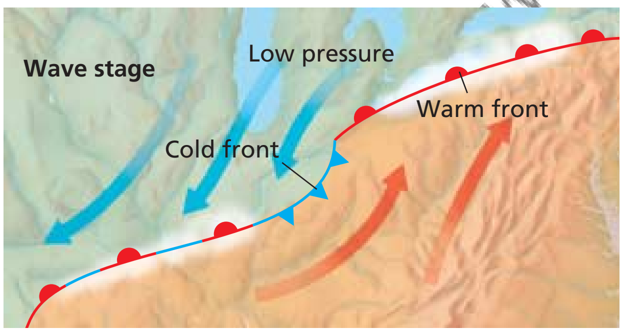
Unlike the air in a midlatitude cyclone, the air of an *anticyclone* sinks and flows outward from a center of high pressure. Because of the Coriolis effect, the circulation of air around an anticyclone is clockwise in the Northern Hemisphere. Anticyclones bring dry weather, because their sinking air does not promote cloud formation. If an anticyclone stagnates over a region for a few days, the anticyclone may cause air pollution problems. After being stationary for a few weeks, anticyclones may cause droughts.

Reading Check **How is the air of an anticyclone different from that of a midlatitude cyclone? (See the Appendix for answers to Reading Checks.)**

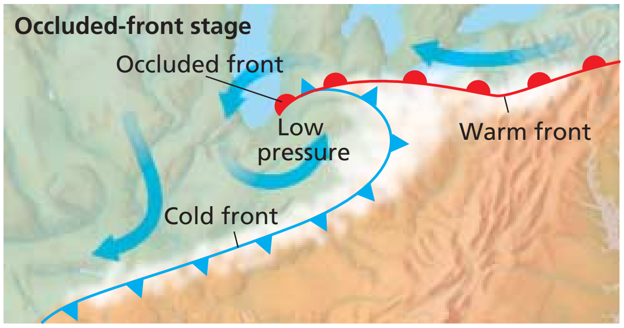
Figure 3 ▶ **Stages of a Midlatitude Cyclone**



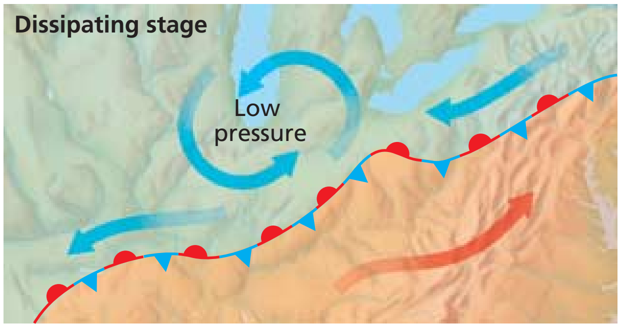
1 Midlatitude cyclones occur along a cold or a stationary front. Winds move parallel to the front but in opposite directions on each side of the front.



2 A wave forms when a bulge of cold air develops and advances slightly ahead of the rest of the front.



3 As the fast-moving part of the cold front overtakes the warm front, an occluded front forms and the storm reaches its highest intensity.



4 Eventually, the system generally loses all of its energy and the midlatitude cyclone dissipates.

Severe Weather

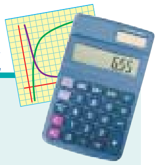
Severe weather is weather that may cause property damage or loss of life. Severe weather may include large quantities of rain, lightning, hail, strong winds, or tornadoes. This type of weather causes billions of dollars in damage each year.

Thunderstorms

A heavy storm that is accompanied by rain, thunder, lightning, and strong winds is called a **thunderstorm.** Thunderstorms develop in three distinct stages. In the first stage, or *cumulus stage,* warm, moist air rises, and the water vapor within the air condenses to form a cumulus cloud. In the next stage, called the *mature stage,* condensation continues as the cloud rises and becomes a dark cumulonimbus cloud. Heavy, torrential rain and hailstones may fall from the cloud. While strong updrafts continue to rise, downdrafts form as air is dragged downward by the falling precipitation. During the final stage, or *dissipating stage,* the strong downdrafts stop air currents from rising. The thunderstorm dissipates as the supply of water vapor decreases.

thunderstorm a usually brief, heavy storm that consists of rain, strong winds, lightning, and thunder

MATHPRACTICE



Thunderstorm Distance The time between when a person sees a lightning strike and when he or she hears thunder indicates how far away the lightning bolt was from that person. Sound travels approximately 1 km in 3 s. The lapse time in seconds divided by 3 is roughly the number of kilometers between the viewer and the lightning. If 27 seconds pass between a flash of lightning and the sound of thunder, how far away was the lightning strike from the viewer?

Lightning

During a thunderstorm, clouds discharge electricity in the form of *lightning*. The released electricity heats the air, and the air expands rapidly and produces the loud noise known as *thunder*. For lightning to occur, the clouds must have areas that carry distinct electrical charges. The upper part of the cloud usually carries a positive charge, while the lower part carries mainly a negative charge. Lightning is a huge spark that travels within the cloud or between the cloud and ground to equalize electrical charges. **Figure 4** shows an example of lightning.

Figure 4 ▶ The average lightning flash lasts only about a quarter of a second, but lightning causes more than $330,000,000 in damage per year in the United States.

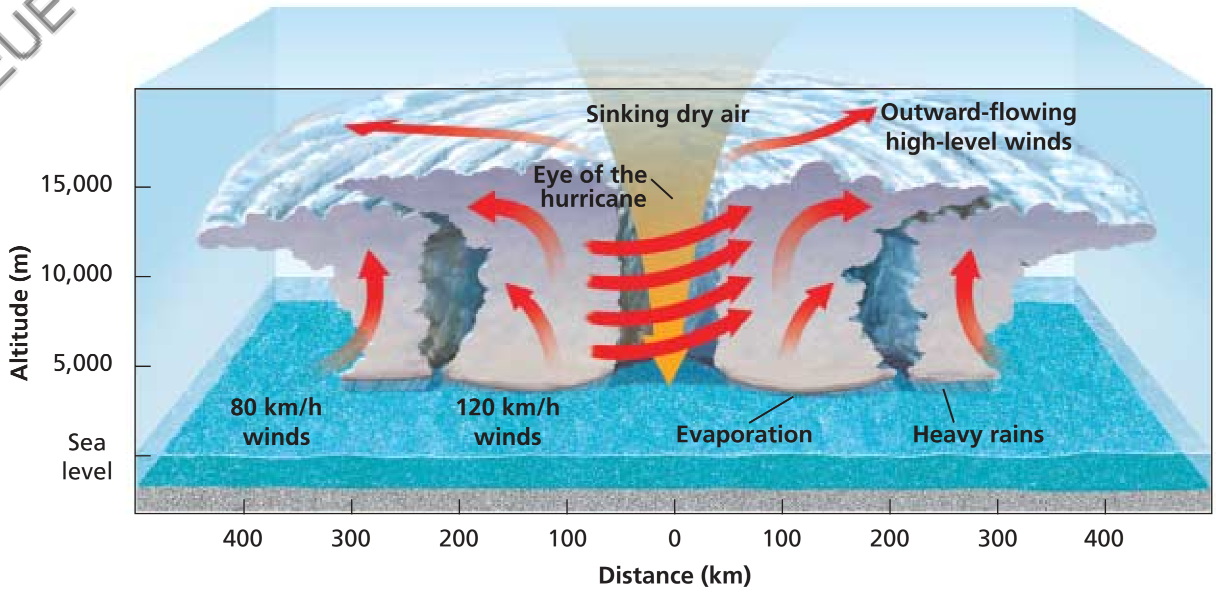


Figure 5 ▶ Although hurricanes are the most destructive storms, the eye at the center of the hurricane is relatively calm.

Hurricanes

Tropical storms differ from midlatitude cyclones in several ways. Tropical storms are concentrated over a small area. They lack warm and cold fronts. Also, they are usually much more violent and destructive than midlatitude cyclones. A tropical storm that has strong wind speeds of more than 120 km/h that spiral in toward its intense low pressure center is called a **hurricane**.

Hurricanes develop over warm, tropical oceans. A hurricane begins when warm, moist air over the ocean rises rapidly. When moisture in the rising warm air condenses, a large amount of energy in the form of latent heat is released. *Latent heat* is heat energy that is absorbed or released during a phase change. This heat increases the force of the rising air.

A fully developed hurricane consists of a series of thick cumulonimbus cloud bands that spiral upward around the center of the storm, as shown in **Figure 5.** Winds increase toward the center, or eye, of the storm and reach speeds of up to 275 km/h along the eyewall. The eye itself, however, is a region of calm, clear, sinking air.

At about 700 km in diameter, hurricanes are the most destructive storms that occur on Earth. The most dangerous aspect of a hurricane is a rising sea level and large waves, called a *storm surge*. A storm surge can submerge vast low-lying coastal areas. This flooding is the reason why most deaths during hurricanes are caused by drowning.

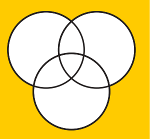
Every hurricane is categorized on the *Safir-Simpson scale* by using several factors. These factors include central pressure, wind speed, and storm surge. The Safir-Simpson scale has five categories. Category 1 storms cause the least damage. Category 5 storms can result in catastrophic damage.

Reading Check **Where do hurricanes develop? (See the Appendix for answers to Reading Checks.)**

hurricane a severe storm that develops over tropical oceans and whose strong winds of more then 120 km/h spiral in toward the intensely low-pressure storm center

Graphic Organizer **Venn Diagram**

Create the Graphic Organizer entitled "Venn Diagram" described in the Skills Handbook section of the Appendix. Label the circles with "Hurricanes," "Cyclones," and "Anticyclones." Then, fill in the diagram with characteristics that each weather event shares with the other weather events.



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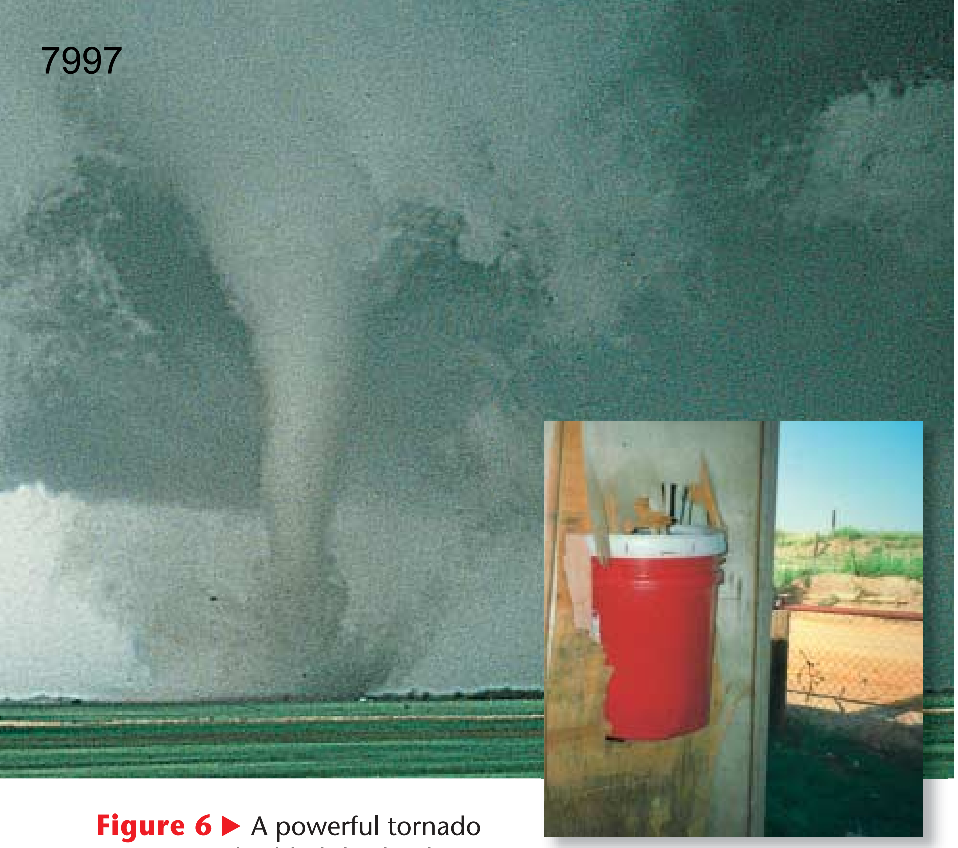


Figure 6 ▶ A powerful tornado in Texas embedded this bucket in a wooden door (inset).

Tornadoes

The smallest, most violent, and shortest-lived severe storm is a tornado. A **tornado** is a destructive, rotating column of air that has very high wind speeds and that is visible as a funnel-shaped cloud, as shown in **Figure 6.**

A tornado forms when a thunderstorm meets high-altitude, horizontal winds. These winds cause the rising air in the thunderstorm to rotate. A storm cloud may develop a narrow, funnel-shaped, rapidly spinning extension that reaches downward and may or may not touch the ground. If the funnel does touch the ground, it generally moves in a wandering, haphazard path. Frequently, the funnel rises and touches down again a short distance away. Tornadoes generally cover paths not more than 100 m wide. Usually, everything in that path is destroyed. Tornadoes occur in many locations, but they are most common in *Tornado Alley* in the late spring or early summer. Tornado Alley stretches from Texas up through the midwestern United States.

The destructive power of a tornado is due to mainly the speed of the winds in the funnel. These winds may reach speeds of more than 400 km/h. Most injuries and deaths caused by tornadoes occur when people are trapped in collapsing buildings or are struck by objects blown by the wind.

tornado a destructive, rotating column of air that has very high wind speeds and that maybe visible as a funnel-shaped cloud

Section 2 Review

1. **Describe** the four main types of fronts.
2. **Compare** the characteristic weather patterns of cold fronts with those of warm fronts.
3. **Identify** the type of front that may form a squall line.
4. **Summarize** how a midlatitude cyclone forms.
5. **Describe** the stages in the development of thunderstorms.
6. **Describe** the stages in the development of hurricanes.
7. **Explain** why tornadoes are destructive.

CRITICAL THINKING

8. **Evaluating Methods** What areas of Earth should meteorologists monitor to detect developing hurricanes? Explain your answer.
9. **Making Comparisons** Compare the destructive power of midlatitude cyclones, hurricanes, and tornadoes in terms of size, wind speed, and duration.

CONCEPT MAPPING

10. Use the following terms to create a concept map: *tornado, hurricane, warm front, squall line, cold front, severe weather, stationary front, front, midlatitude cyclone,* and *occluded front.*

Section 3 Weather Instruments

Weather observations are based on a variety of measurements, including atmospheric pressure, humidity, temperature, wind speed, and precipitation. These measurements are made with special instruments. Meteorologists then use the measurements to forecast weather patterns.

OBJECTIVES

- **Identify** four instruments that measure lower-atmospheric weather conditions.
- **Describe** how scientists measure conditions in the upper atmosphere.
- **Explain** how computers help scientists understand weather.

KEY TERMS

thermometer
barometer
anemometer
wind vane
radiosonde
radar

Measuring Lower-Atmospheric Conditions

During the course of a day, the lower-atmospheric conditions at a given location can change drastically. Meteorologists use the magnitude and speed of these changes to make predictions of future weather events. To obtain accurate data from the lower atmosphere, scientists use instruments such as those shown in **Figure 1.**

Air Temperature

An instrument that measures and indicates temperature is called a **thermometer.** A common type of thermometer uses a liquid—usually mercury or alcohol—sealed in a glass tube to indicate temperature. A rise in temperature causes the liquid to expand and fill more of the tube. A drop in temperature causes the liquid to contract and fill less of the tube. A scale marked on the glass tube indicates the temperature.

Another type of thermometer is an *electrical thermometer.* As the temperature rises, the electric current that flows through the material of the electrical thermometer increases and is translated into temperature readings. A *thermistor,* or thermal resistor, is a type of electrical thermometer that responds very quickly to temperature changes. For this reason, thermistors are extremely useful where temperature change occurs rapidly.

thermometer an instrument that measures and indicates temperature

Figure 1 ▶ Weather instruments, such as these at Elk Mountain weather research facility in Wyoming, indicate wind speed and direction.

Figure 2 ▶ A meteorologist uses an anemometer during Hurricane Luis to measure wind speed.

Air Pressure

Changes in air pressure affect air masses. The approach of a front is usually indicated by a drop in air pressure. Scientists use instruments called **barometers** to measure atmospheric pressure.

Wind Speed

An instrument called an **anemometer** (AN uh MAHM uht uhr) measures wind speed. A typical anemometer consists of small cups that are attached by spokes to a shaft that rotates freely. The wind pushes against the cups and causes them to rotate, as shown in **Figure 2.** This rotation triggers an electrical signal that registers the wind speed in meters per second or in miles per hour.

barometer an instrument that measures atmospheric pressure

anemometer an instrument used to measure wind speed

wind vane an instrument used to determine direction of the wind

Wind Direction

The direction of the wind is determined by using an instrument called a **wind vane.** The wind vane is commonly an arrow-shaped device that turns freely on a pole as the tail catches the wind. Wind direction may be described by using one of 16 compass directions, such as north-northeast. Wind direction also may be recorded in degrees by moving clockwise and beginning with 0° at the north. Thus, east is 90°, south is 180°, and west is 270°.

Reading Check **Which instrument is used to measure air pressure? (See the Appendix for answers to Reading Checks.)**

Quick LAB **15 min**

Wind Chill

Procedure

1. Place a **23 cm × 33 cm pan** on a level table. Fill the pan to a depth of 1 cm with **room temperature water.**
2. Lay a **thermometer** in the center of the pan with the bulb submerged. After 5 minutes, record the water temperature. Do not touch the thermometer.
3. Place an **electric fan** facing the pan and a few centimeters from the pan. Turn on the fan at a low speed. **CAUTION** Do not get the fan or cord wet.
4. Record the water temperature every minute until the temperature remains constant.

Analysis

1. How does the moving air affect the temperature of the water?
2. If the moving air is the same temperature as the still air in the room, what causes the water temperature to change?
3. How would you dress on a cool, windy day to stay comfortable? Explain your answer.

Connection to TECHNOLOGY

Doppler Radar

Lightning strikes near this Doppler radar facility in Oklahoma.

Conventional radar helps scientists estimate the distance to a storm and the intensity of the storm by measuring how many radio waves return. To learn more about storms, meteorologists developed a different form of radar to study weather. This form of radar, called *Doppler radar,* can measure not only the distance to a storm and the storm's overall direction and speed but also the direction that rain droplets or ice particles inside the storm are moving. This information allows scientists to identify conditions inside the storm.

Doppler radar uses the Doppler effect to read the apparent shift in wavelength of reflected radio waves as the particles that the waves reflect from move. You may have experienced the Doppler effect when an ambulance sped by you. The sound of the siren appeared to change from high-pitched as the ambulance approached to low-pitched as it moved farther away. Because the wind causes the rain or ice particles to move around, the frequency of the radar signals they reflect also appear to shift. The Doppler radar measures that apparent frequency shift. Computer models then convert this information into an overall picture of the movement of the particles.

The use of Doppler radar allows meteorologists to identify dangerous conditions within a storm and to track the movement of these features. This ability allows meteorologists to warn communities of weather threats in time to save lives.

Measuring Upper-Atmospheric Conditions

Conditions of the atmosphere near Earth's surface are only a part of the complete weather picture. Scientists use several instruments to measure conditions in the upper atmosphere to obtain a better understanding of local and global weather patterns.

Radiosonde

An instrument package that is carried high into the atmosphere by a helium-filled weather balloon to measure relative humidity, air pressure, and air temperature is called a **radiosonde.** The radiosonde sends measurements as radio waves to a receiver that records the information. The path of the balloon is tracked to determine the direction and speed of high-altitude winds. When the balloon reaches a very high altitude, the balloon expands and bursts, and the radiosonde parachutes back to Earth.

radiosonde a package of instruments that is carried aloft by balloons to measure upper atmospheric conditions, including temperature, dew point, and wind velocity

radar **ra**dio **d**etection **a**nd **r**anging, a system that uses reflected radio waves to determine the velocity and location of objects

Radar

Another instrument for determining weather conditions in the atmosphere is radar. **Radar,** which stands for **ra**dio **d**etection **a**nd **r**anging, is a system that uses reflected radio waves to determine the velocity and location of objects. For example, large particles of water in the atmosphere reflect radar pulses. Thus, precipitation and storms, such as thunderstorms, tornadoes, and hurricanes, are visible on a radar screen. The newest Doppler radar can indicate the precise location, movement, and extent of a storm. It can also indicate the intensity of precipitation and wind patterns within a storm.

Figure 3 ▶ This satellite image captured Hurricane Andrew in 1992 as it approached Louisiana.

Weather Satellites

Instruments carried by weather satellites also collect important information about the atmosphere. Satellite images, such as the one shown in **Figure 3**, provide weather information for regions where observations cannot be made from the ground.

The direction and speed of the wind at the level of the clouds can also be measured by examining a continuous sequence of cloud images. For night monitoring, satellite images made by using infrared energy reveal temperatures at the tops of clouds, at the surface of the land, and at the ocean surface. Satellite instruments can also measure marine conditions. For example, the instruments can measure the temperature and flow of ocean currents and the height of ocean waves.

Computers

Meteorologists also use supercomputers to understand the weather. Before computers were available, solving the mathematical equations that describe the behavior of the atmosphere was very difficult, and sometimes impossible. In addition to solving many of these equations, computers can store weather data from around the world. These data can provide information that is useful in forecasting weather changes. Computers can also store weather records for quick retrieval. In the future, powerful computers may greatly improve weather forecasts and provide a much better understanding of the atmosphere.

Section 3 Review

1. **Identify** four instruments scientists use to measure lower-atmospheric conditions.
2. **Explain** why scientists are interested in weather conditions in the upper atmosphere.
3. **Describe** the instruments used to measure conditions in the upper atmosphere.
4. **Explain** how meteorologists send weather instruments into the upper atmosphere.
5. **Summarize** how satellites help meteorologists study weather.
6. **Summarize** how computers help scientists study weather.

CRITICAL THINKING

7. **Recognizing Relationships** Wind is named according to the direction from which it blows. Why would a meteorologist need to know the direction wind is blowing from?
8. **Making Inferences** If weather instruments were moved from a location in a valley to the top of a hill, what changes would you expect in the data? Explain your answer.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *thermometer, barometer, anemometer, radar, radiosonde, satellite, upper atmosphere, lower atmosphere,* and *weather instruments.*

Section 4 Forecasting the Weather

Predicting the weather has challenged people for thousands of years. People in many early civilizations attributed control of weather conditions, such as wind, rain, and thunder, to gods. Some people attempted to forecast the weather by using the position of the moon and stars as the basis for their predictions.

Scientific weather forecasting began with the invention of basic weather instruments, such as the thermometer and the barometer. The invention of the telegraph in 1844 enabled meteorologists to share information about weather conditions quickly and led to the creation of national weather services. For example, the United States formed a weather-forecasting agency called the Weather Bureau. In 1970, it was renamed the *National Weather Service.* Because weather events in the United States commonly originate beyond U.S. borders, the National Weather Service exchanges weather data with other nations around the world.

OBJECTIVES

- **Explain** how weather stations communicate weather data.
- **Explain** how a weather map is created.
- **Explain** how computer models help meteorologists forecast weather.
- **List** three types of weather that meteorologists have attempted to control.

KEY TERM

station model

Global Weather Monitoring

Weather observers at stations around the world report weather conditions frequently, sometimes hourly. They record the barometric pressure and how it has changed as well as the speed and direction of surface wind. They measure precipitation, temperature, and humidity. They note the type, amount, and height of cloud cover. Observers also record visibility and general weather conditions. Similar data are gathered continuously by automated observing systems. Each station in the system sends its data to a collection center. Weather centers around the world exchange the weather information they have collected.

The World Meteorological Organization (WMO) sponsors a program called *World Weather Watch* to promote the rapid exchange of weather information. The organization helps developing countries establish or improve their meteorological services, as shown in **Figure 1.** It also offers advice on the effect of weather on natural resources and on human activities, such as farming and transportation. WMO was founded in 1873 and is now part of the United Nations.

Figure 1 ▶ One major role of the World Meteorological Organization is to train professionals to use weather instruments, such as this Bobson spectrophotometer installed at Maun, Botswana.

Weather Maps

The data that weather stations collect are transferred onto weather maps. Weather maps allow meteorologists to understand the current weather and to predict future weather events. To communicate weather data on a weather map, meteorologists use symbols and colors. These symbols and colors are understood and used by meteorologists around the world.

Weather Symbols

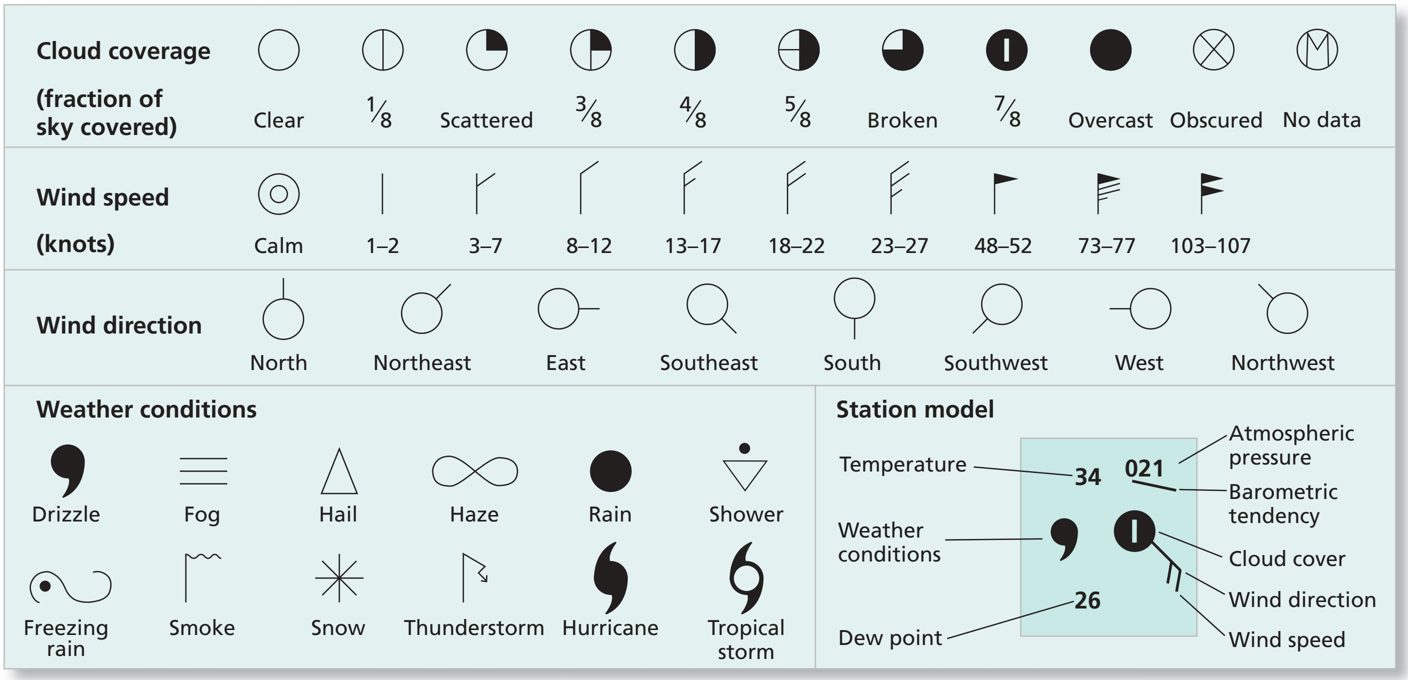
station model a pattern of meteorological symbols that represents the weather at a particular observing station and that is recorded on a weather map

On some weather maps, clusters of meteorological symbols show weather conditions at the locations of weather stations. Such a cluster of symbols is called a **station model.** Common weather symbols describe cloud cover, wind speed, wind direction, and weather conditions, such as type of precipitation and storm activity. These symbols and a station model are shown in **Figure 2.** Notice that the symbols for cloud cover, wind speed, and wind direction are combined in one symbol in the station model.

Other information included in the station model are the air temperature and the dew point. The *dew point* is the temperature to which the air must cool in order for more water to condense than to evaporate in a given amount of time. The dew point indicates how high the humidity of the air is, or how much water is in the air.

The station model also indicates the atmospheric pressure by using a three-digit number in the upper right hand corner. If this number starts with 0, then the pressure is higher than 1,000 millibars. The position of a straight line under this figure—horizontal or angled up or down—shows whether the atmospheric pressure is steady or is rising or falling.

Figure 2 ▶ Meteorologists use symbols to indicate weather conditions. The station model (lower right) shows an example of conditions around a weather station.



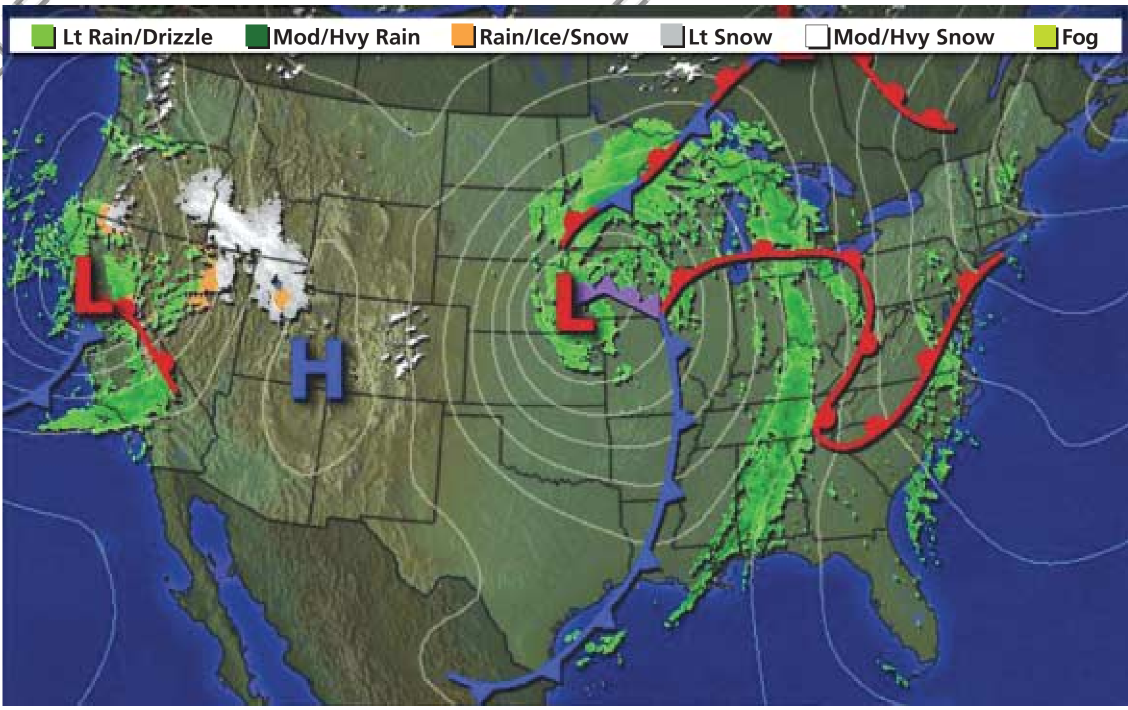


Figure 3 ▶ A typical weather map shows isobars, highs and lows, fronts, and precipitation. ***In what parts of the United States are low-pressure areas located?***

Plotting Temperature and Pressure

Scientists use lines on weather maps to connect points of equal measurement. Lines that connect points of equal temperature are called *isotherms*. Lines that connect points of equal atmospheric pressure are called *isobars*. The spacing and shape of the isobars help meteorologists interpret their observations about the speed and direction of the wind. Closely spaced isobars indicate a rapid change in pressure and high wind speeds. Widely spaced isobars generally indicate a gradual change in pressure and low wind speeds. Isobars that form circles indicate centers of high or low air pressure. Such centers that are marked with an *H* represent high pressure, as you can see in **Figure 3.** Centers that are marked with an *L* represent low pressure.

Plotting Fronts and Precipitation

Most weather maps mark the locations of fronts and areas of precipitation. The weather map in **Figure 3** shows examples of a warm front, a cold front, an occluded front, and a stationary front. Fronts are identified by sharp changes in wind speed and direction, temperature, or humidity.

Areas of precipitation are commonly marked by using colors or symbols. Different forms of precipitation are represented by different colors or symbols. For example, the weather map in **Figure 3** indicates light rain by using light green, while snow is represented by gray and white. Some weather maps use colors to represent different amounts of precipitation so that the amount of precipitation that falls in different areas can be compared.

Reading Check **How do meteorologists mark precipitation on a weather map? (See the Appendix for answers to Reading Checks.)**

Figure 4 ▶ With the help of Doppler radar, meteorologists can track severe storms from radar stations, such as this one in Kansas.

Weather Forecasts

To forecast the weather, meteorologists regularly plot the intensity and path of weather systems on maps. Meteorologists then study the most recent weather map and compare it with maps from previous hours. This comparison allows them to follow the progress of large weather systems. By following the progress of weather systems, meteorologist can forecast the weather.

Weather Data

Doppler radar, shown in **Figure 4**, and satellite images supply important information, such as intensity of precipitation. Meteorologists input these data into computers to create weather models. Computer models can show the possible weather conditions for several days. However, meteorologists must carefully interpret these models because computer predictions are based on generalized descriptions.

Some computer models may be better at predicting precipitation for a particular area, while other computer models may be better at predicting temperature and pressure. Comparing models helps meteorologists better predict weather. If weather information on two or more models is similar, a meteorologist will be more confident about the weather prediction. By using all of the weather data available, meteorologists can issue an accurate forecast of the weather.

Temperature, wind direction, wind speed, cloudiness, and precipitation can usually be forecasted accurately. But it is often difficult to predict precisely when precipitation will occur or the exact amount. By using computers, scientists can manipulate data on temperature and pressure to simulate errors in measuring these data. Forecasts are then compared to see if slight data changes cause substantial differences in forecasts. From what they learn, meteorologists can make more accurate forecasts.

Reading Check **Why do meteorologists compare models? (See the Appendix for answers to Reading Checks.)**

QuickLAB 10 min

Gathering Weather Data

Procedure

1. Select an area outside your school building that is in the shade away from buildings and pavement.
2. Use a **thermometer** to measure the air temperature.
3. Estimate the percentage of cloud cover.
4. Estimate wind speed. Use a **magnetic compass** to estimate the wind direction.

Analysis

1. What are the current weather conditions outside your school?
2. Using the data you collected, create a station model that describes the weather at your school.

Types of Forecasts

Meteorologists make four types of forecasts. *Nowcasts* mainly use radar and enable forecasters to focus on timing precipitation and tracking severe weather. *Daily forecasts* predict weather conditions for a 48-hour period. *Extended forecasts* look ahead 3 to 7 days. *Medium range forecasts* look ahead 8 to 14 days. *Long-range forecasts* cover monthly and seasonal periods.

Accurate weather forecasts can be made for 0 to 7 days. However, accuracy decreases with each day. Extended forecasts of 8 to 14 days are made by computer analysis of slowly changing large-scale movements of air. These changes help meteorologists predict the general weather pattern. For example, the changes indicate if temperature will be warmer or cooler than normal or if conditions will be dry or wet.

Severe Weather Watches and Warnings

One main goal of meteorology is to reduce the amount of destruction caused by severe weather by forecasting severe weather early. When meteorologists forecast severe weather, they issue warnings and watches. A *watch* is issued when the conditions are ideal for severe weather. A *warning* is given when severe weather has been spotted or is expected within 24 hours. Meteorologists use these alerts to provide people in areas facing severe weather with instructions on how to be safer during the event. **Table 1** lists some safety tips to follow for different types of severe weather.

Table 1 ▼

Severe Weather Safety Tips

Type of weather	How to prepare	Safety during the event
Thunderstorm	Have a storm preparedness kit that includes a portable radio, fresh batteries, flashlights, rain gear, blankets, bottled water, canned food, and medicines.	Listen to weather updates. Stay or go indoors. Avoid electrical appliances, running water, metal pipes, and phone lines. If outside, avoid tall objects, stay away from bodies of water, and get into a car, if possible.
Tornado	Have a storm preparedness kit as described above. Plan and practice a safety route.	Listen to weather updates. Stay or go indoors. Go to a basement, storm cellar, or small, inner room, closet, or hallway that has no windows. Stay away from areas that are likely to have flying debris or other dangers. If outside, lie in a low-lying area. Protect your head and neck.
Hurricane	Have a storm preparedness kit as described above. Secure loose objects, doors, and windows. Plan and practice an evacuation route.	Listen to weather updates. Be prepared to follow instructions and planned evacuation routes. Stay indoors and away from areas that are likely to have flying debris or other dangers.
Blizzard	Have a storm preparedness kit as described above. Make sure you have a way to safely make heat in the event of power outages.	Listen to weather updates. Stay or go indoors. Dress warmly. Avoid walking or driving in icy conditions.

Figure 5 ▶ An outdoor ultrahigh-voltage laboratory generates artificial lightning to test its affects on electrical utility equipment. Research has led to the development of equipment that suffers less damage from lightning.

Controlling the Weather

Some meteorologists are investigating methods of controlling rain, hail, and lightning. Currently, the most researched method for producing rain has been *cloud seeding*. In this process, particles are added to clouds to cause the clouds to precipitate. Cloud seeding can also be used to prevent more-severe precipitation. Scientists in Russia have used cloud seeding with some success on potential hail clouds by causing rain, rather than hail, to fall.

Hurricane Control

Hurricanes have also been seeded with freezing nuclei in an effort to reduce the intensity of the storm. During Project Stormfury, which took place from 1962 to 1983, four hurricanes were seeded, and the project had mixed results. Scientists have, for the most part, abandoned storm and hurricane control because it is not an attainable goal with existing technology. They do, however, continue to seed clouds to cause precipitation.

Lightning Control

Attempts have also been made to control lightning. Seeding of potential lightning storms with silver-iodide nuclei has seemed to modify the occurrence of lightning. However, no conclusive results have been obtained. Researchers have also generated artificial lightning at research facilities to learn more about lightning and how it affects objects it strikes. An example of one of these facilities is shown in **Figure 5.**

Section 4 Review

1. **Summarize** how global weather is monitored.
2. **Explain** how a weather map is made.
3. **Explain** which would show stronger winds—widely spaced isobars or closely spaced isobars.
4. **List** six different pieces of information that you can obtain from a station model.
5. **Explain** why meteorologists compare new weather maps and weather maps that are 24 hours old.
6. **Describe** how computer models help meteorologists forecast weather.
7. **List** three types of weather that meteorologists have tried to control.

CRITICAL THINKING

8. **Making Inferences** Why might cloud seeding reduce the amount of hail from a storm?
9. **Making Reasoned Judgment** Seeding hurricanes may or may not yield positive results. Each attempt costs a lot of money. If you were in charge of deciding whether to seed a potentially dangerous hurricane, what factors would you consider when deciding what to do? Explain your answer.

CONCEPT MAPPING

10. Use the following terms to create a concept map: *isobar, isotherm, weather map, forecast, watch, warning, station model,* and *meteorological symbol.*

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Chapter 24 Highlights

Sections

1 Air Masses

Key Terms

air mass, 601

Key Concepts

- An air mass is a large body of air that has uniform temperature and humidity.
- Air masses can be described as polar, tropical, continental, and maritime. Their characteristics, which affect how they influence weather in North America, depend on their source region.

2 Fronts

Key Terms

cold front, 605
warm front, 606
stationary front, 606
occluded front, 606
midlatitude cyclone, 606
thunderstorm, 608
hurricane , 609
tornado, 610

Key Concepts

- Cold and warm fronts are associated with characteristic weather conditions.
- A midlatitude cyclone is a storm that has a low-pressure center, rotating winds, and high-speed winds.
- Hurricanes, thunderstorms, and tornadoes are violent, destructive storms that are caused by the interaction of air masses with different properties.

3 Weather Instruments

Key Terms

thermometer, 611
barometer, 612
anemometer, 612
wind vane, 612
radiosonde, 613
radar, 613

Key Concepts

- Thermometers, barometers, anemometers, and wind vanes measure lower-atmospheric weather conditions.
- Radiosondes, radar, satellite equipment, and computers are used to measure upper-atmospheric weather conditions.
- Computers are used to solve complicated mathematical equations that describe weather.

4 Forecasting the Weather

Key Terms

station model, 616

Key Concepts

- Meteorologists prepare weather maps that are based on information from weather stations around the world.
- Meteorologists use different instruments to make daily and long-term forecasts of the weather.
- Meteorologists have attempted to control rain, hurricanes, and lightning with only limited success.

Chapter 24 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *air mass*
2. *stationary front*
3. *station model*

For each pair of terms, explain how the meanings of the terms differ.

4. *midlatitude cyclone* and *hurricane*
5. *wind vane* and *anemometer*
6. *radiosonde* and *radar*
7. *cold front* and *warm front*
8. *thermometer* and *barometer*

Understanding Key Concepts

9. Which of the following is information you would not find from a station model?
   a. precipitation
   b. cloud cover
   c. front
   d. wind speed

10. Continental polar Canadian air masses generally move
    a. southeasterly.
    b. northerly.
    c. northeasterly.
    d. westerly.

11. The type of front that forms when two air masses move parallel to the front between them is called
    a. stationary.
    b. occluded.
    c. polar.
    d. warm.

12. The type of front that is completely lifted off the ground by cold air is called
    a. cold.
    b. occluded.
    c. polar.
    d. warm.

13. The eye of a hurricane is a region of
    a. hailstorms.
    b. torrential rainfall.
    c. calm, clear air.
    d. strong winds.

14. The winds of a midlatitude cyclone blow in circular paths around a
    a. front.
    b. low-pressure center.
    c. high-pressure center.
    d. jet stream.

15. In the mature stage of a thunderstorm, a cumulus cloud grows until it becomes a
    a. stratocumulus cloud.
    b. altocumulus cloud.
    c. cumulonimbus cloud.
    d. cirrocumulus cloud.

16. An instrument package attached to a weather balloon is
    a. an anemometer.
    b. a wind vane.
    c. a thermograph
    d. a radiosonde.

17. The lines that connect points of equal atmospheric pressure on a weather map are called
    a. isobars.
    b. isotherms.
    c. highs.
    d. lows.

Short Answer

18. Describe the weather before and after an occluded front.

19. What causes lightning?

20. What is the most likely location for hurricane development? Explain your answer.

21. How could a meteorologist use a station model to determine whether a cold front is approaching?

22. Identify the wind direction of wind given as 315°. What direction would a wind vane point in that case?

23. Identify the type of air mass that would most likely be responsible if the air in your region is warm and dry. What letters designate this air mass?

Critical Thinking

24. Making Predictions Suppose people on Vancouver Island, off the west coast of Canada, hear reports of a midlatitude cyclone in the Gulf of Alaska. Is it likely that the midlatitude cyclone will reach their area? Explain why.

25. Making Inferences Suppose a hurricane is passing over a Caribbean island. Suddenly, the rain and winds stop and the air becomes calm and clear. Can a person safely go outside? Explain your answer.

26. Applying Ideas Is it safe to be in an automobile during a tornado? Explain your answer.

27. Making Inferences An air traffic controller is monitoring nearby airplanes by radar. The controller warns an incoming pilot of a storm a few miles away. How did radar help the controller detect the storm?

Concept Mapping

28. Use the following terms to create a concept map: *air mass, front, warm front, cold front, cyclones, thunderstorm, thermometer, hurricane, barometer,* and *anemometer.*

Math Skills

29. Making Calculations The temperature at a station is given as 47°F . Using the equation, °C = 5/9 × (°F − 32), find the temperature in degrees Celsius.

30. Making Calculations An average of 124 tornadoes occur each year in Texas. If that is equivalent to 4.7 tornadoes per 10,000 mi^2, what is the area of Texas in square miles?

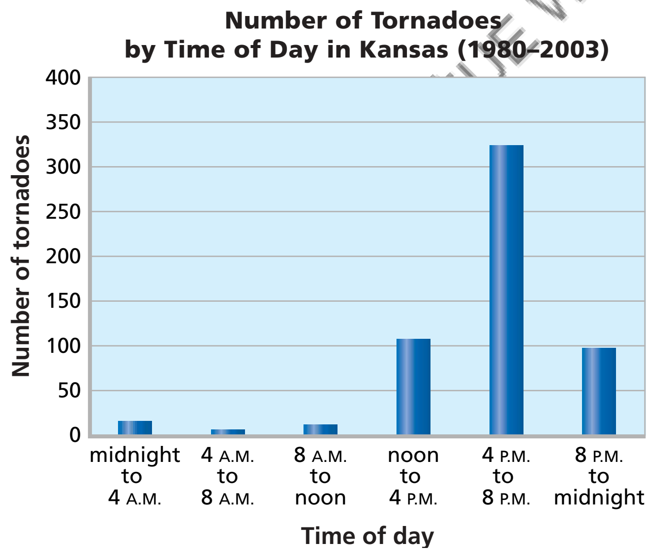
Writing Skills

31. Creative Writing Imagine that you are traveling with friends through the desert in the southwestern United States and a thunderstorm occurs. You then tell them about the type of air mass that may have brought the storm. Describe what the stages might look like by types of clouds formed, types of precipitation, and sky color.

32. Communicating Main Ideas Explain how cP and mT air masses travel across the United States, and explain why this information helps meteorologists make forecasts.

Interpreting Graphics

The graph below shows the number of tornadoes that happened in Kansas at different times of day between January 1980 and July 2003. Use the graph to answer the questions that follow.



33. During which time of day did the least tornadoes occur?

34. Would Kansas students be more likely to experience a tornado while they are at school or while they are at home?

35. During which time of day did most tornadoes occur? Why would most tornadoes happen at this time of day?

Chapter 24 Standardized Test Prep

Understanding Concepts

Directions (1–5): **For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 What tool do meteorologists use to analyze particle movements within storms?
A. an anemometer
B. a radiosonde balloon
C. doppler radar
D. satellite imaging

2 What kind of front forms when two air masses move parallel to the boundary located between them?
F. an occluded front
G. a polar front
H. a warm front
I. a stationary front

3 Which of the following weather systems commonly forms over warm tropical oceans?
A. thunderstorms
B. hurricanes
C. tornadoes
D. anticyclones

4 What often happens to maritime air masses as they move inland over mountainous country?
F. They bring warm, dry weather conditions.
G. They produce clouds and hurricanes.
H. They bring cold, dry weather conditions.
I. They lose moisture passing over mountains.

5 What type of air mass originates over the southwestern desert of the United States in summer?
A. continental polar air mass
B. continental tropical air mass
C. maritime polar air mass
D. maritime tropical air mass

Directions (6–7): **For *each* question, write a short response.**

6 What type of front is formed when a warm air mass is overtaken by a cold air mass, which causes the warm air to lift above the cold air?

7 What do closely spaced isobars indicate about the wind on a weather map?

Reading Skills

Directions (8–10): **Read the passage below. Then, answer the questions.**

Tornado Alley

Though tornadoes are not unique to the area, the violent, rotating, funnel-shaped clouds and their trails of destruction are so common in the central United States that the area is called Tornado Alley. These severe thunderstorms and the super-cell tornadoes that they spawn are formed when warm, moist air from the Gulf of Mexico becomes trapped beneath hot, dry air from the southwest desert region. Above that hot, dry air, cold, dry air sweeps in from the Rocky Mountains. The interaction between high-altitude winds and thunderstorms creates the funnel-shaped vortex of high-speed winds known as a tornado.

The largest outbreak of tornadoes in this region occurred in April of 1974. Before the storms ended, 148 separate tornadoes roared through 13 different states. More than 300 people lost their lives, and another 5,000 people were injured. More than 1,300 buildings were destroyed.

8 Why is the central part of the United States also known as Tornado Alley?
A. Tornadoes in the area move in straight lines known as alleys.
B. The destruction left by tornadoes made the area look like an unkempt alley.
C. Areas between buildings are the safest places to be during of a tornado.
D. Tornadoes are common occurances in this particular part of the country.

9 Which of the following statements can be inferred from the information in the passage?
F. In the United States, tornadoes are more common in some areas than in other areas.
G. Tornadoes can form only in the area near the Rocky Mountains.
H. All tornadoes cause injuries to humans.
I. Multiple tornadoes are a rare occurance.

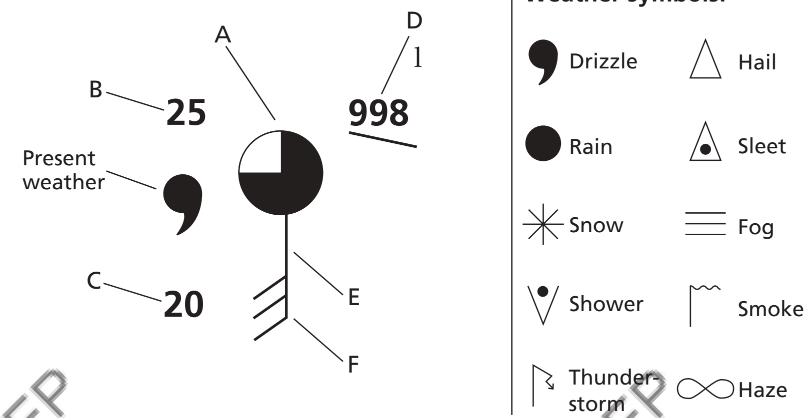
10 What makes tornadoes so much more difficult to predict than other severe weather systems?

Interpreting Graphics

***Directions (11–14):* For *each* question below, record the correct answer on a separate sheet of paper.**

The diagram below shows a station model. Use this diagram to answer questions 11 and 12.

Interpreting a Station Model



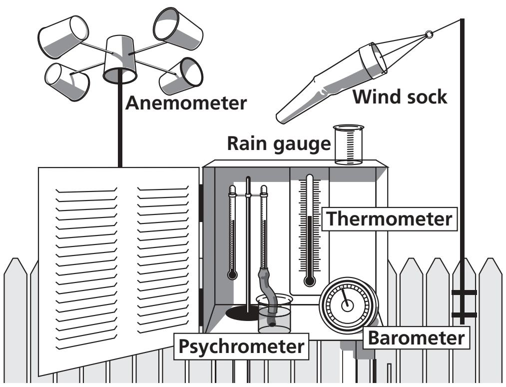
11 What letter represents the current barometric reading shown in the model?

A. letter A
B. letter B
C. letter C
D. letter D

12 What weather information do the symbols indicated by the letters E and F provide? Interpret this part of the station model.

The diagram below shows a home weather station. Use this diagram to answer questions 13 and 14.

Weather Instruments



13 Which of the following weather instruments shown uses the cooling effect of evaporation to take measurements?

A. a rain gauge
B. a psychrometer
C. a wind sock
D. a thermometer

14 Describe how an anemometer is used to calculate wind speed.

Test TIP

Sometimes, only one part of a diagram, graph, or table is needed to answer a question. In such cases, focus on only that information to answer the question.

Chapter 24

Skills Practice Lab

Objectives

- **Construct** a pressure and temperature map.
- **Interpret** a weather map.
- **Explain** how weather patterns are related to pressure systems.

Materials

paper
pencil
pencils, colored, red, blue

Weather Map Interpretation

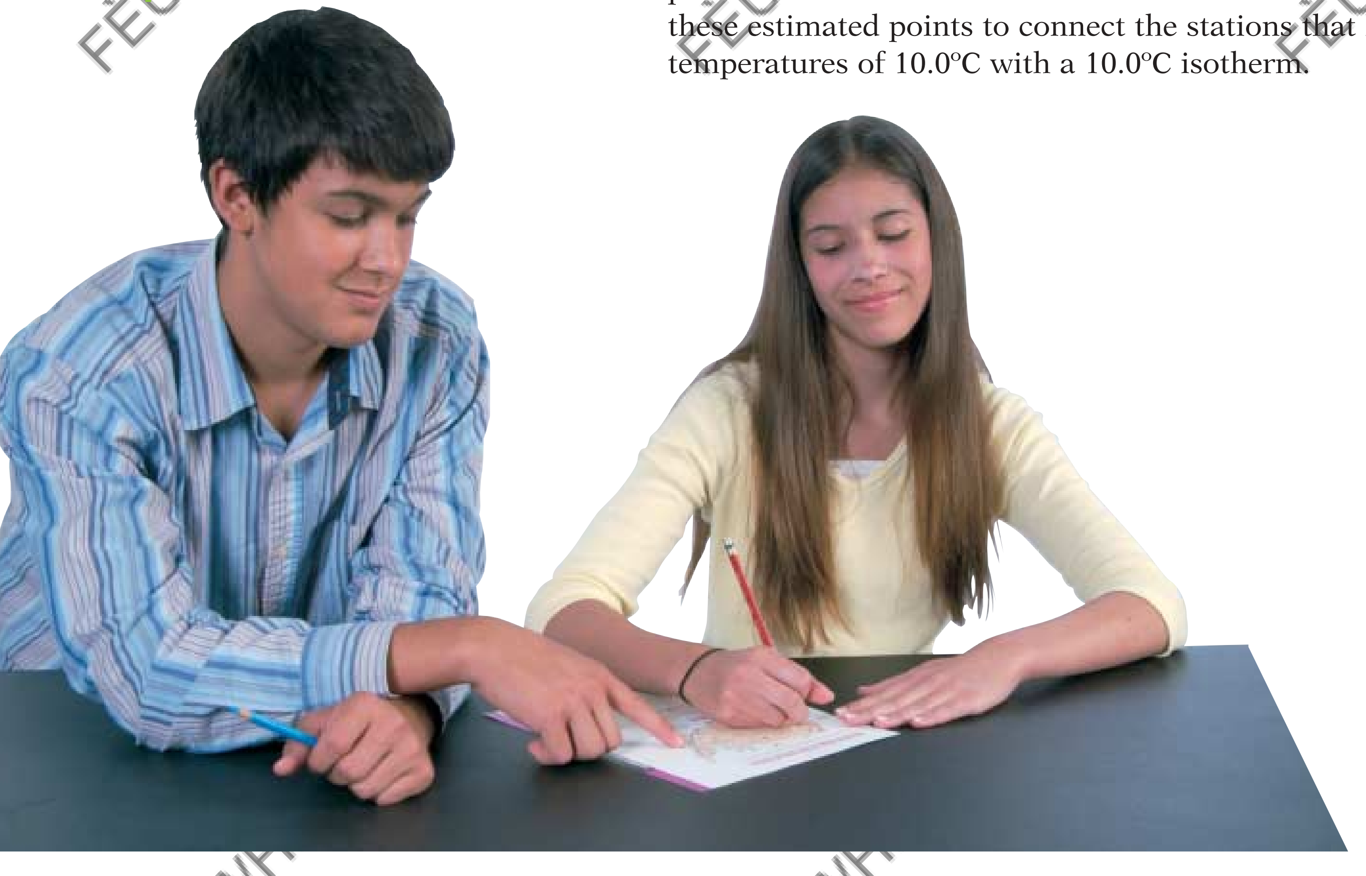
Weather maps use various map symbols and lines to illustrate the weather conditions in an area at a given time. In this lab, you will study the symbols used on a weather map to gain an understanding of the relationships between temperature, pressure, and winds.

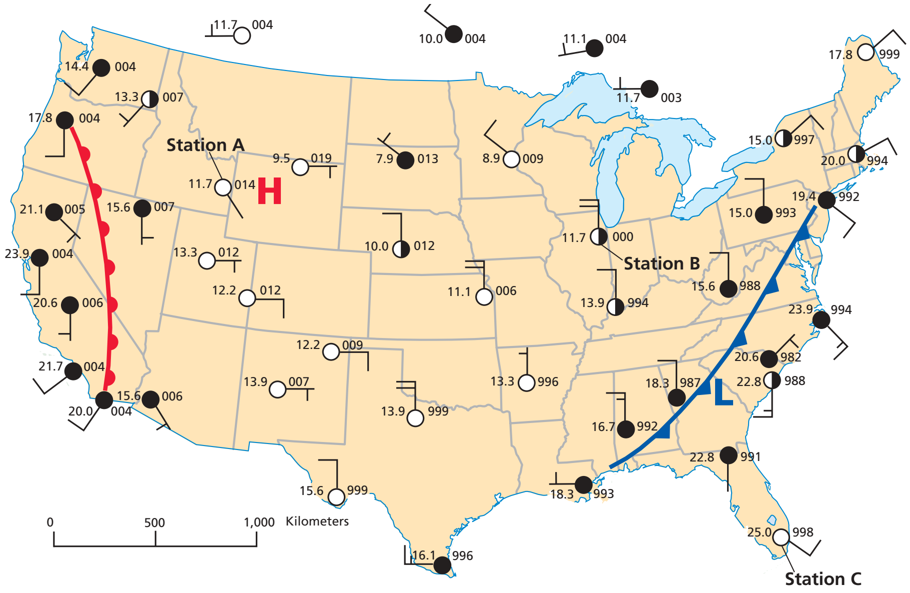
PROCEDURE

1. Make a copy of the weather map on the following page. This map can also be found in the Reference Tables section of the Appendix. You will use the map symbols on the same page of the Appendix to interpret the weather map. The higher number associated with each station on the map represents atmospheric pressure. The lower number represents temperature.

2. On your copy of the weather map, find stations that have a temperature of 10.0ºC. Use a red pencil to draw a light line through these stations. If two adjacent stations have temperatures above and below 10ºC, there is an estimated point between them that is 10.0ºC. Draw a line through these estimated points to connect the stations that have temperatures of 10.0ºC with a 10.0ºC isotherm.

Step 2





Step 1

3. Using the same method as in step 2, draw isotherms for every two degrees of temperature. Examples are isotherms of 12.0°C, 14.0°C, and 16.0°C. Label each isotherm with the temperature it represents.

4. Find a station that has a barometric pressure of 1,004 millibars. Use a blue pencil, and follow the same method that you used in step 2 to create a 1,004 millibars isobar.

6. Using the same method as in step 3, lightly draw isobars for every 4 millibars of pressure. Examples are isobars of 1,000 mb, 1,008 mb, and 1,012 mb. Label each isobar with the pressure it represents.

ANALYSIS AND CONCLUSION

1. **Identifying Trends** What is the lowest temperature for which you have drawn an isotherm? What is the highest temperature for which you have drawn an isotherm? Is either isotherm a closed loop? If so, which one?

2. **Making Inferences** Is the air mass that is identified by the closed isotherms a cold air mass or a warm air mass? Explain your answer.

3. **Analyzing Data** Is there a shift in wind direction associated with either front shown on your map? Describe the shift.

4. **Identifying Trends** What is the value of the lowest-pressure isobar that was drawn? What is the value of the highest-pressure isobar that was drawn? Is either isobar a closed loop? If so, which one?

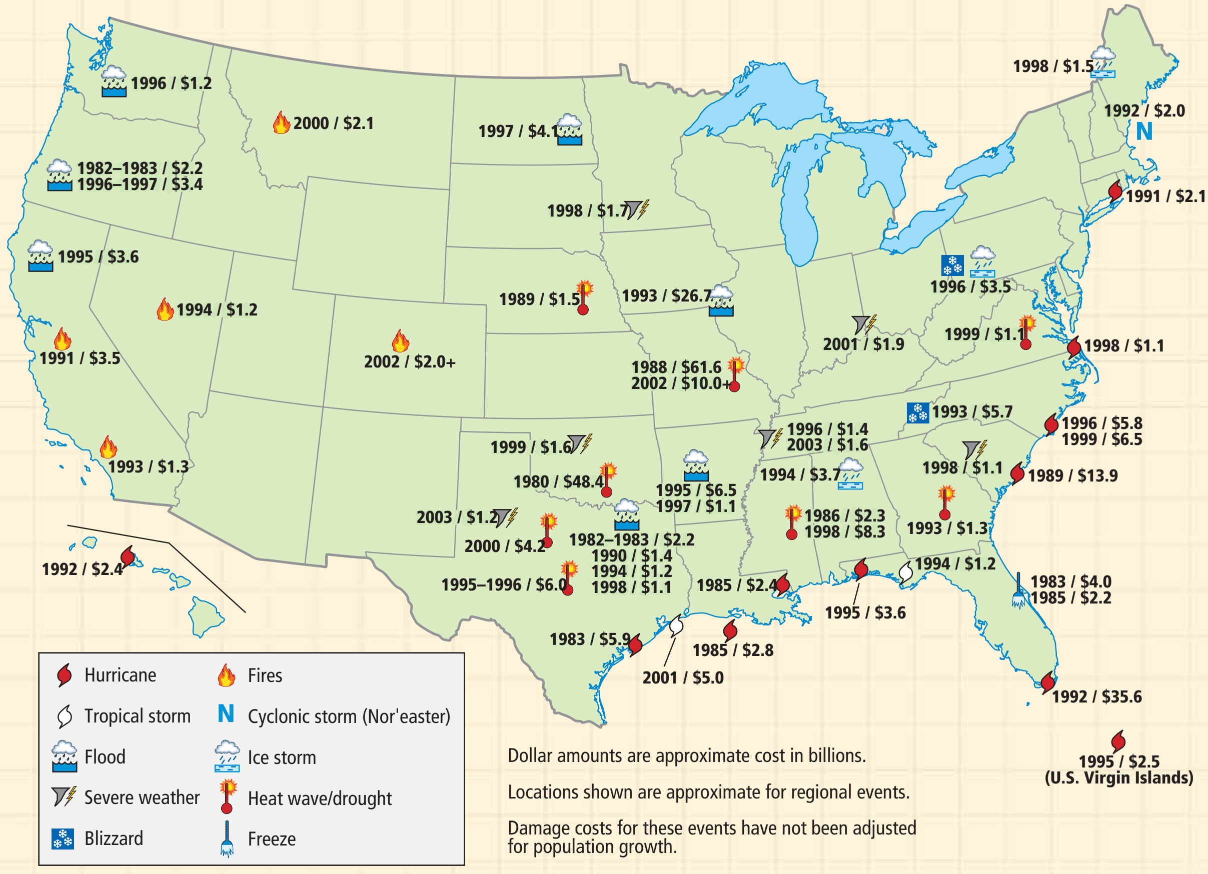
5. **Drawing Conclusions** At the time that the map represents, were there any areas of low pressure? of high pressure? Identify these areas. What weather conditions would you expect to find in those areas?

Extension

1. **Making Predictions** Predict the weather conditions at Station A 24 hours after the observations for your map were made. Record your predictions in a table with columns for pressure, wind direction, wind speed, temperature, and sky condition. Also, make and record predictions for Station B and Station C.

MAPS in Action

Weather-Related Disasters, 1980–2003



Map Skills Activity

This map shows the types and locations of weather disasters in the United States that caused at least $1 billion in damage. Use the map to answer the questions below.

1. **Using the Key** How many severe weather events caused more than $10 billion in damage between 1980 and 2003?
2. **Analyzing Data** Which type of weather disaster is more common—floods or fires?
3. **Making Comparisons** How do the types of disasters that happen in the western United States differ from the types of disasters that happen in the eastern United States? Explain why this difference exists.
4. **Inferring Relationships** Why might an ice storm in Alabama cause more damage than an ice storm in Maine?
5. **Identifying Trends** Almost all hurricane damage during this period happened along the coasts of the Atlantic Ocean and the Gulf of Mexico. Explain why.
6. **Analyzing Relationships** In 1996, a blizzard and floods caused $3.5 billion in damage in Ohio, Pennsylvania, and West Virginia. How might these events be related? Explain your answer.
7. **Analyzing Processes** Explain why fires are included in this map of weather-related disasters.

Career Focus

Meteorologist

When a hurricane threatens, most people flee, but not Shirley Murillo. Murillo boards a research aircraft and flies into the hurricane! As the plane flies through the hurricane, instruments record wind speed, wind direction, temperature, and air pressure.

Through the Eye of the Storm

Most of the flight is remarkably smooth, until the aircraft reaches the eyewall. The eyewall is a donutlike ring of turbulent thunderstorms that surround the calm eye of the storm. Once past the eyewall, the plane enters calm air. "We fly for hours going in and out of the eye, dropping instruments … into the eye," says Murillo. Some of these instruments measure air pressure. These data help hurricane forecasters decide if the storm is becoming weaker or stronger.

Improving Hurricane Forecasting

When she is not flying into hurricanes, Murillo is in her office at the Hurricane Research Division of the Atlantic Oceanographic and Meteorological Laboratory, an NOAA facility in Miami, Florida. Murillo studies how hurricane wind speeds change at landfall.

Murillo's research helps hurricane forecasters at the National Hurricane Center create their forecasts and advisories. Emergency managers also use it to determine areas along the coast that need to be evacuated. Scientists also use Murillo's work to predict storm surge, the onshore rush of seawater caused by a hurricane's high winds and low pressure.

"Flying into a hurricane is a thrill. The data that are collected … help save lives and property."

—Shirley Murillo

Rewards and Benefits

There is no doubt that Murillo's job can be exciting—and gratifying. "The most rewarding part of my job is the way in which our understanding of hurricanes and our improvement in forecasting benefit the scientific community and the public."

◀ The eye of the storm can be seen just below the plane *NOAA P-3* as it flies through Hurricane Caroline.

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Topic: Careers in Earth Science
SciLinks code: HQ60222

8017

Chapter 25 Climate

Sections

1 Factors That Affect Climate

2 Climate Zones

3 Climate Change

What You'll Learn

- What factors affect climate
- How regional climates vary
- How scientists study past climate changes and predict future climate changes

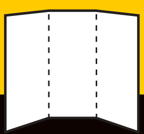
Why It's Relevant

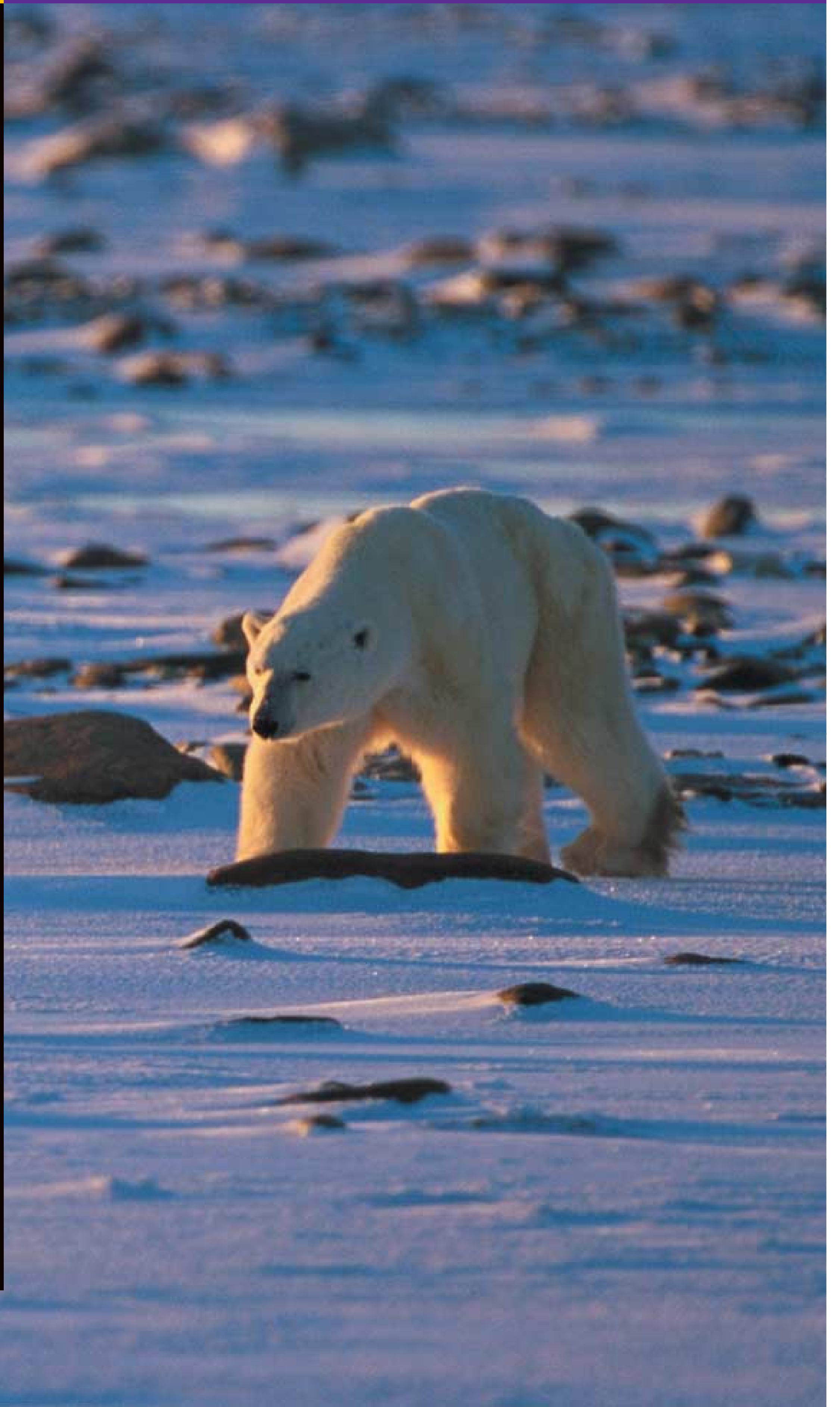
Earth sustains life because the temperature and moisture conditions are right. By learning about climate, we can understand factors that might affect life on Earth.

PRE-READING ACTIVITY

FOLDNOTES

Tri-Fold Before you read this chapter, create the FoldNote entitled "TriFold" described in the Skills Handbook section of the Appendix. Write what you know about climate in the column labeled "Know." Then, write what you want to know in the column labeled "Want." As you read the chapter, write what you learn about climate in the column labeled "Learn."





▶ Thick fur and other adaptations allow polar bears to survive and thrive in the freezing temperatures of the tundra climate.

Section 1 Factors That Affect Climate

The average weather conditions for an area over a long period of time are referred to as **climate.** Climate is different from weather in that weather is the condition of the atmosphere at a particular time. Weather conditions, such as temperature, humidity, wind, and precipitation, vary from day to day. To understand climate, scientists study the features that define different climates.

OBJECTIVES

- **Identify** two major factors used to describe climate.
- **Explain** how latitude determines the amount of solar energy received on Earth.
- **Describe** how the different rates at which land and water are heated affect climate.
- **Explain** the effects of topography on climate.

KEY TERMS

climate
specific heat
El Niño
monsoon

Temperature and Precipitation

Climates are chiefly described by using average temperature and precipitation. To estimate the average daily temperature, add the high and low temperatures of the day and divide by two. The monthly average is the average of all of the daily averages for a given month. The yearly average temperature can be found by averaging the 12 monthly averages. However, using only average temperatures to describe climate can be misleading. As you can see in **Figure 1,** areas that have similar average temperatures may have very different temperature ranges. Another way scientists describe climate is by using the *yearly temperature range,* or the difference between the highest and lowest monthly averages.

Another major factor that affects climate is precipitation. It is also described by using monthly and yearly averages as well as ranges. As with temperature, average yearly precipitation alone cannot describe a climate. The months that have the largest amount of precipitation are important for determining climate. When describing climates, extremes of temperature and precipitation as well as averages have to be considered. The factors that have the greatest influence on both temperature and precipitation are latitude, heat absorption and release, and topography.

climate the average weather conditions in an area over a long period of time

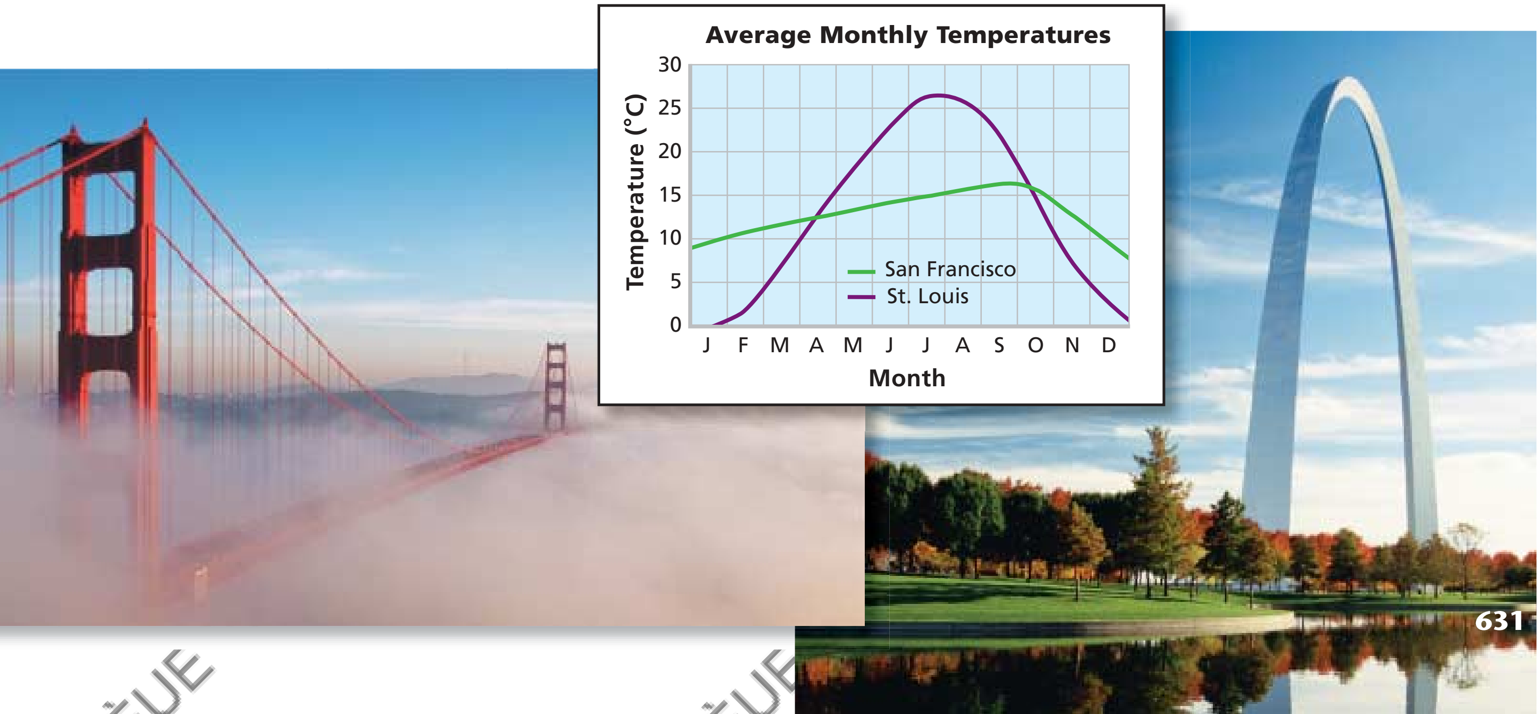


Figure 1 ▶ Both St. Louis and San Francisco have the same average yearly temperature. However, St. Louis (right) has a climate of cold winters and hot summers, while San Francisco (left) has a generally mild climate all year.

8019

Latitude

One of the most important factors that determines a region's climate is latitude. Different latitudes on Earth's surface receive different amounts of solar energy. Solar energy determines the temperature and wind patterns of an area, which influence the average annual temperature and precipitation.

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Topic: What Affects Climate?
SciLinks code: HQ61652

Solar Energy

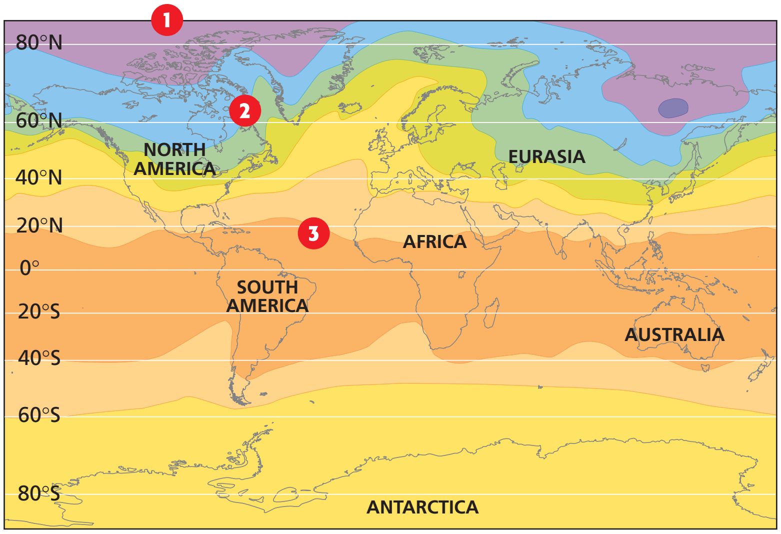
The higher the latitude of an area is, the smaller the angle at which the sun's rays hit Earth is and the smaller the amount of solar energy received by the area is. At the equator, or 0° latitude, the sun's rays hit Earth at a 90° angle. So, temperatures at the equator are high. At the poles, or 90° latitudes, the sun's rays hit Earth at a smaller angle, and solar energy is spread over a large area. So, temperatures at the poles are low.

Because Earth's axis is tilted, the angle at which the sun's rays hit an area changes as Earth orbits the sun. During winter in the Northern Hemisphere, the northern half of Earth is tilted away from the sun. Thus, light that reaches the Northern Hemisphere hits Earth's surface at a smaller angle than it does in summer, when the axis is tilted toward the sun. Because of the tilt of Earth's axis during winter in the Northern Hemisphere, areas of Earth at higher northern latitudes directly face the sun for less time than during the summer. As a result, the days are shorter and the temperatures are lower during the winter months than during the summer months. **Figure 2** describes these effects.

Figure 2 ▶ Average Sea-Level Temperatures During Winter in the Northern Hemisphere

1 In polar regions, the amount of daylight varies from 24 hours of daylight in the summer to 0 hours in the winter. Thus, the annual temperature range is very large, but the daily temperature ranges are very small.

2 At middle latitudes, the sun's rays strike Earth at an angle of less than 90°. The energy of the rays is spread over a large area. Thus, average yearly temperatures at middle latitudes are lower than those at the equator. The lengths of days and nights vary less than they do at the poles. Therefore, the yearly temperature range is large.



Temperatures (°C)	
21 to 32	−23 to −12
10 to 21	−34 to −23
−1 to 10	−46 to −34
−12 to −1	Below −46

3 At the equator, the sun's rays always strike Earth at a very large angle—nearly 90° for much of the year. In equatorial regions, both days and nights are about 12 hours long throughout the year. So, these regions have steady, high temperatures year-round.

Global Wind Patterns

Because Earth receives different amounts of solar energy at different latitudes, belts of cool, dense air form at latitudes near the poles, while belts of warm, less dense air form near the equator. Because cool air is dense, it forms regions of high pressure, while warm air forms regions of low pressure. Differences in air pressure create wind. Because air pressure is affected by latitude, the atmosphere is made up of global wind belts that run parallel to lines of latitude. Winds affect many weather conditions, such as precipitation, temperature, and cloud cover. Thus, regions that have different global wind belts often have different climates.

In the equatorial belt of low pressure, called the *doldrums,* the air rises and cools, and water vapor condenses. Thus, this region generally has large amounts of precipitation. The amount of precipitation generally decreases as latitude increases. In the regions between about 20° and 30° latitude in both hemispheres, or the *subtropical highs,* the air sinks, warms, and dries. Thus, little precipitation occurs in these regions. Most of the world's deserts are located in these regions. In the middle latitudes, at about 45° to 60° latitude in both hemispheres, warm tropical air meets cold polar air, which leads to belts of greater precipitation. In the high-pressure areas, above 60° latitude, the air masses are cold and dry, and average precipitation is low.

As seasons change, global wind belts shift in a north or south direction, as shown in **Figure 3.** As the wind and pressure belts shift, the belts of precipitation associated with them also shift.

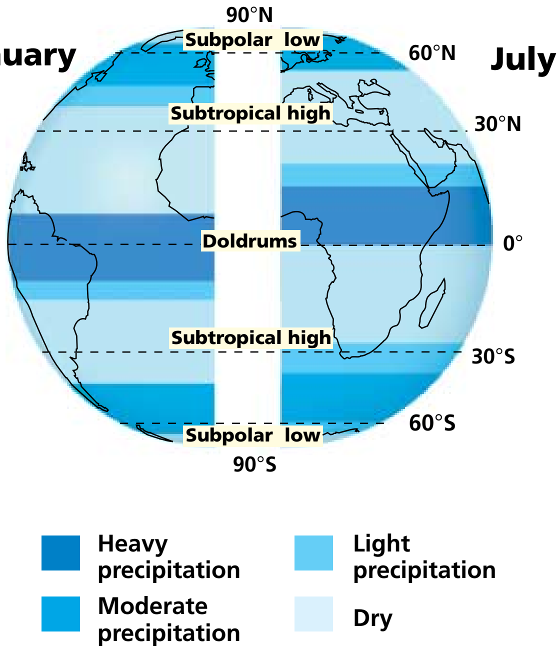


Figure 3 ▶ During winter in the Northern Hemisphere, global wind and precipitation belts shift to the south.

Heat Absorption and Release

Latitude and cloud cover affect the amount of solar energy that an area receives. However, different areas absorb and release heat differently. Land heats faster than water and thus can reach higher temperatures in the same amount of time. One reason for this difference is that the land surface is solid and unmoving. Surface ocean water, on the other hand, is liquid and moves continuously. Waves, currents, and other movements continuously replace warm surface water with cooler water from the ocean depths. This action prevents the surface temperature of the water from increasing rapidly. However, the surface temperature of the land can continue to increase as more solar energy is received. In turn, the temperature of the land or ocean influences the amount of heat that the air above the land or ocean absorbs or releases. The temperature of the air then affects the climate of the area.

Reading Check **How do wind and ocean currents affect the surface temperature of oceans? (See the Appendix for answers to Reading Checks.)**

Specific Heat and Evaporation

Even if not in motion, water warms more slowly than land does. Water also releases heat energy more slowly than land does. This is because the specific heat of water is higher than that of land. **Specific heat** is the amount of energy needed to change the temperature of 1 g of a substance by 1°C. A given mass of water requires more energy than land of the same mass does to experience an increase in temperature of the same number of degrees.

The average temperatures of land and water at the same latitude also vary because of differences in the loss of heat through evaporation. Evaporation affects water surfaces much more than it affects land surfaces.

specific heat the quantity of heat required to raise a unit mass of homogeneous material 1 K or 1°C in a specified way given constant pressure and volume

Ocean Currents

The temperature of ocean currents that come in contact with the air influences the amount of heat absorbed or released by the air. If winds consistently blow toward shore, ocean currents have a strong effect on air masses over land. For example, the combination of a warm Atlantic current and steady westerly winds gives northwestern Europe a high average temperature for its latitude. In contrast, the warm Gulf Stream has little effect on the eastern coast of the United States. This is because westerly winds usually blow the Gulf Stream and its warm tropical air away from the coast.

Reading Check **Why does land heat faster than water does? (See the Appendix for answers to Reading Checks.)**

MATHPRACTICE

Specific Heat

Use the following equation to calculate the amount of energy needed to heat 200 kg of water 6°C given that the specific heat of water is 4,186 J/kg•K.

energy = specific heat × mass × temperature change

QuickLAB 15 min

Evaporation

Procedure

1. On a piece of paper, make a data table similar to the one shown here.

Dish	Temperature	Amount of water evaporated
1		
2		
3		

2. Assemble a ring stand on a table. Use a meterstick to place the support rings at heights of 20 cm and 40 cm above the base. Position a portable clamp lamp that has an incandescent bulb directly over the rings and at a height of 60 cm.
3. Place three Petri dishes or watch glasses as follows: one on the base of the stand and one on each of the two rings.
4. Take three thermometers, and lay one across each dish. Turn on the lamp. Use a stopwatch to record the temperature every 3 min for 9 min.
5. Remove the thermometers, and add 30 mL of water to each of the three dishes.
6. Keep the lamp on and over the dishes for 24 h.
7. Turn off the lamp. Carefully pour the water from the first dish into a graduated cylinder, and record any change in volume. Repeat this process for the other two dishes.

Analysis

1. At what distance from the lamp did the most water evaporate? the least water evaporate?
2. Explain the relationship between temperature and the rate of evaporation.
3. Explain why puddles of water dry out much more quickly in summer than they do in fall or winter.

El Niño–Southern Oscillation

The *El Niño–Southern Oscillation*, or *ENSO*, is a cycle of changing wind and water-current patterns in the Pacific Ocean. Every 3 to 10 years, **El Niño,** which is the warm-water phase of the ENSO, causes surface-water temperatures along the west coast of South America to rise. The event changes the interaction of the ocean and the atmosphere, which can change global weather patterns. During El Niño, typhoons, cyclones, and floods may occur in the Pacific Ocean region and southeastern United States. Droughts may strike other areas around the world, such as Indonesia and Australia. The ENSO also has a cool-water phase called *La Niña*. La Niña also affects weather patterns.

El Niño the warm-water phase of the El Niño–Southern Oscillation; a periodic occurrence in the eastern Pacific Ocean in which the surface-water temperature becomes unusually warm

monsoon a seasonal wind that blows toward the land in the summer, bringing heavy rains, and that blows away from the land in the winter, bringing dry weather

Seasonal Winds

Temperature differences between the land and the oceans sometimes cause winds to shift seasonally in some regions. During the summer, the land warms more quickly than the ocean. The warm air rises and is replaced by cool air from the ocean. Thus, the wind moves toward the land. During the winter, the land loses heat more quickly than the ocean does, and the cool air flows away from the land. Thus, the wind moves seaward. Such seasonal winds are called **monsoons.**

Monsoon climates, such as that in southern Asia, are caused by heating and cooling of the northern Indian peninsula. In the winter, continental winds bring dry weather and sometimes drought. In the summer, winds carry moisture to the land from the ocean and cause heavy rainfall and flooding, as shown in **Figure 4.** Monsoon conditions also occur in eastern Asia and affect the tropical regions of Australia and East Africa.

Figure 4 ▶ Effects of Monsoon Climates

Because monsoon rains cause regular flooding, such as this flood in eastern India, people who live in monsoon regions have adapted to living in flood conditions.

People who live in monsoon climates must adjust to periodic droughts, such as the drought that affected this cropland in southern India.

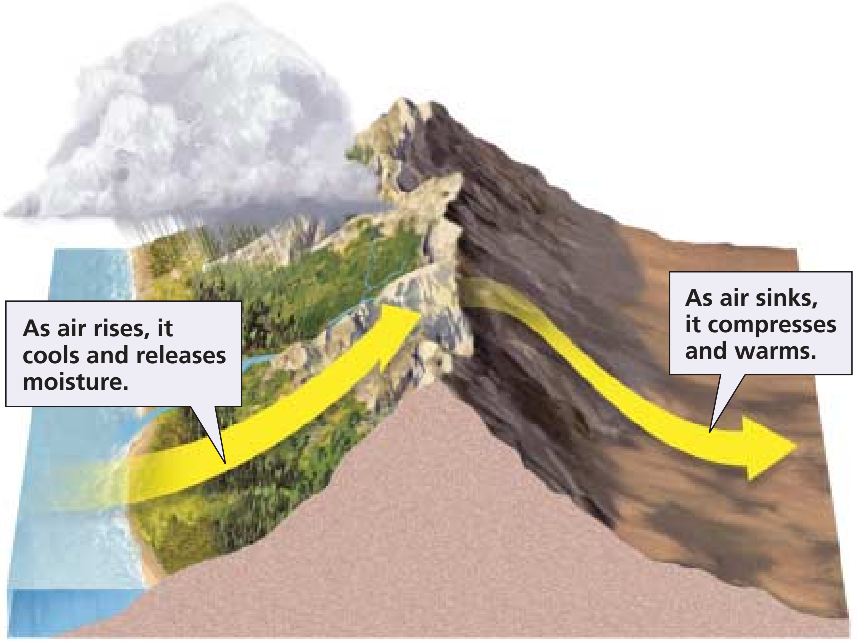


Figure 5 ▶ Mountains cause air to rise, cool, and lose moisture as the air passes over the mountains. This process affects the climate on both sides of the mountain.

Topography

The surface features of the land, or *topography,* also influence climate. Topographical features, such as mountains, can control the flow of air through a region.

Elevation

The elevation, or height of landforms above sea level, produces distinct temperature changes. Temperature generally decreases as elevation increases. For example, for every 100 m increase in elevation, the average temperature decreases by 0.7°C. Even along the equator, the peaks of high mountains can be cold enough to be covered with snow.

Rain Shadows

When a moving air mass encounters a mountain range, the air mass rises, cools, and loses most of its moisture through precipitation, as shown in **Figure 5.** As a result, the air that flows down the other side of the range is usually warm and dry. This effect is called a *rain shadow*. One type of warm, dry wind that forms in this way is the *foehn* (FAYN), a dry wind that flows down the slopes of the Alps. Similar dry, warm winds that flow down the eastern slopes of the Rocky Mountains are called *chinooks*.

Section 1 Review

1. **Identify** two factors that are used to describe climate.
2. **Explain** how latitude determines the amount of solar energy received on Earth.
3. **Describe** how latitude determines wind patterns.
4. **Describe** how the different rates at which land and water are heated affect climate.
5. **Explain** the El Niño–Southern Oscillation cycle.
6. **Summarize** the conditions that cause monsoons.
7. **Explain** how elevation affects climate.
8. **Describe** a rain shadow and the resulting local winds.

CRITICAL THINKING

9. **Making Inferences** If land and water had the same specific heat, how might climate be different around the world?
10. **Analyzing Processes** On a mountain, are you likely to find more vegetation on the side facing prevailing winds or on the side facing away from them?
11. **Recognizing Relationships** Why might you find snow-capped mountains in Hawaii even though Hawaii is closer to the equator than Florida is?

CONCEPT MAPPING

12. Use the following terms to create a concept map: *climate, temperature range, wind, doldrums, subtropical high, monsoon, El Niño,* and *topography*.

ENVIRONMENTAL CONNECTION

Section 2 Climate Zones

Earth has three major types of climate zones: tropical, middle-latitude, and polar. Each zone has distinct temperature characteristics, including a specific range of temperatures. Each of these zones has several types of climates because the amount of precipitation within each zone varies.

OBJECTIVES

- **Describe** the three types of tropical climates.
- **Describe** the five types of middle-latitude climates.
- **Describe** the three types of polar climates.
- **Explain** why city climates may differ from rural climates.

KEY TERMS

tropical climate
middle-latitude climate
polar climate
microclimate

Tropical Climates

Climates that are characterized by high temperatures and are located in the equatorial region are referred to as **tropical climates.** These climates have an average monthly temperature of at least 18°C, even during the coldest month of the year. Within the tropical zone, there are three types of tropical climates: tropical rain forest, tropical desert, and savanna. These climates are described in **Table 1.**

Tropical rain-forest climates are humid and warm and support a diverse variety of life including dense, rain-forest vegetation. The warm, moist, rising air produces an annual rainfall of 200 cm. Central Africa, the Amazon River basin of South America, Central America, and Southeast Asia have areas that have tropical rain-forest climates.

tropical climate a climate characterized by high temperatures and heavy precipitation during at least part of the year; typical of equatorial regions

Tropical desert climates receive less than 25 cm of precipitation every year and have little or no vegetation. The largest belt of tropical deserts extends across north Africa and southwestern Asia.

Savanna climates support open grasslands that have drought-resistant trees and shrubs. Savannas have very wet summers and very dry winters. Savanna climates are located in South America, Africa, Southeast Asia, and northern Australia.

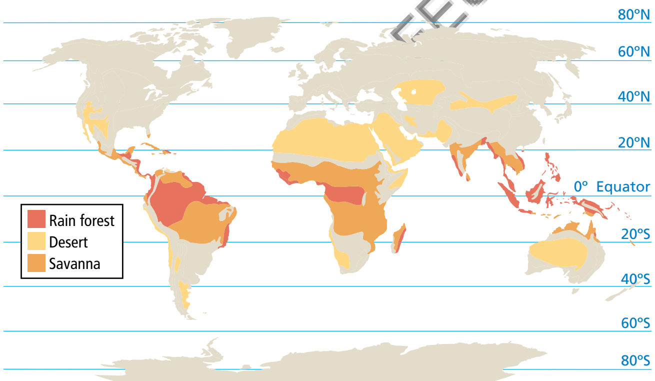
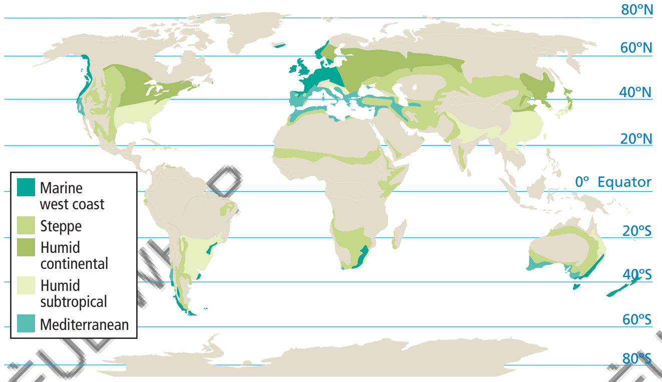


Table 1 ▼

Tropical Climates		
Climate	**Temperature and precipitation**	**Description**
Rain forest	small temperature range; annual rainfall of 200 cm	characterized by dense, lush vegetation; broadleaf plants; and high biodiversity
Desert	large temperature range, hot days, and cold nights; annual rainfall of less than 25 cm	characterized by little to no vegetation and organisms adapted to dry conditions
Savanna	small temperature range; annual rainfall of 50 cm; alternating wet and dry periods	characterized by open grasslands that have clumps of drought-resistant shrubs

Table 2 ▼

Middle-Latitude Climates		
Climate	**Temperature and precipitation**	**Description**
Marine west coast	low annual temperature range; frequent rainfall throughout the year	characterized by deciduous trees and dense forests; mild winters and summers
Steppe	large annual temperature range; annual precipitation of less than 40 cm	characterized by drought-resistant vegetation; cold, dry winters and warm, wet summers
Humid continental	large annual temperature range; annual precipitation of greater than 75 cm	characterized by a wide variety of vegetation and evergreen trees; variable weather
Humid subtropical	large annual temperature range; annual precipitation of 75 to 165 cm	characterized by broadleaf and evergreen trees; high humidity
Mediterranean	low annual temperature range; average annual precipitation of about 40 cm	characterized by broadleaf and evergreen trees; long, dry summers and mild, wet winters



Middle-Latitude Climates

Climates that have an average maximum temperature of 8°C in the coldest month and an average minimum temperature of 10°C in the warmest month are referred to as **middle-latitude climates.** There are five middle-latitude climates, which are described in **Table 2.**

Marine west coast climates receive about 60 to 150 cm of precipitation annually. The average temperature is 20°C in the summer and 7°C in the winter. The Pacific Northwest of the United States has a marine west coast climate.

Steppe climates are dry climates that receive less than 40 cm of precipitation per year. The average temperature is about 23°C. The winters are very cold and have an average temperature of –1°C. The Great Plains of the United States has a steppe climate.

The *humid continental climate* and *humid subtropical climate* have a high annual precipitation. However, the humid continental has a much greater temperature range between the summers and winters than the humid subtropical. In the United States, the humid subtropical climate is in the southeast and the humid continental climate is located in the northeast.

The *mediterranean climate* is a mild climate that has a small temperature range between summer and winter. This climate is named after the sea between Africa and Europe, where this climate is located. However, this climate is also located along the coast of central and southern California.

middle-latitude climate a climate that has a maximum average temperature of 8°C in the coldest month and a minimum average temperature of 10°C in the warmest month

Reading Check **Which subclimates have a high annual precipitation? (See the Appendix for answers to Reading Checks.)**

Figure 1 ▶ Subarctic climates, as shown here at Tombstone Valley in Yukon, Canada, support sparse tree growth.

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Topic: Polar Climates
SciLinks code: HQ61175

Polar Climates

The climates of the polar regions are referred to as the **polar climates.** There are three types of polar climates: the subarctic climate, shown in **Figure 1,** the tundra climate, and the polar icecap climate. The *subarctic climate* has the largest annual temperature range of all climates. The average difference between summer and winter temperatures in the subarctic climate is 63°C. The *tundra climate* has a smaller annual temperature range than the subarctic climate does. But the average temperature of the tundra is colder than that of the subarctic climate. In the *polar icecap climate,* most of the land surface and much of the ocean are covered in thick sheets of ice year-round. The average temperature in these regions never rises above freezing. The polar climates are described in **Table 3.**

polar climate a climate that is characterized by average temperatures that are near or below freezing; typical of polar regions

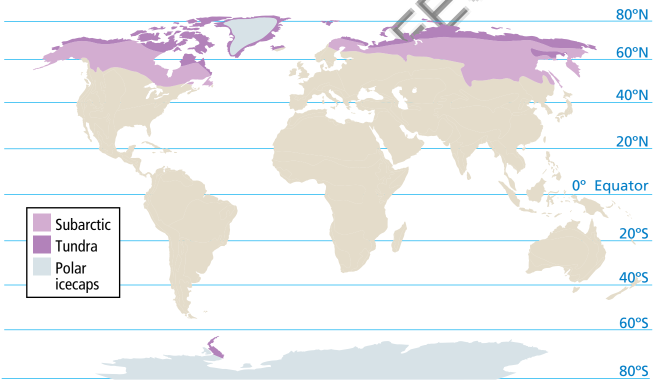


Table 3 ▼

Polar Climates		
Climate	**Temperature and precipitation**	**Description**
Subarctic	largest annual temperature range (63°C); annual precipitation of 25 to 50 cm	characterized by evergreen trees; brief, cool summers and long, cold winters
Tundra	average temperature below 4°C; annual precipitation of 25 cm	characterized by treeless plains; nine months of temperatures below freezing
Polar icecaps	average temperature below 0°C; low annual precipitation	characterized by little or no life; temperatures below freezing year-round and high winds

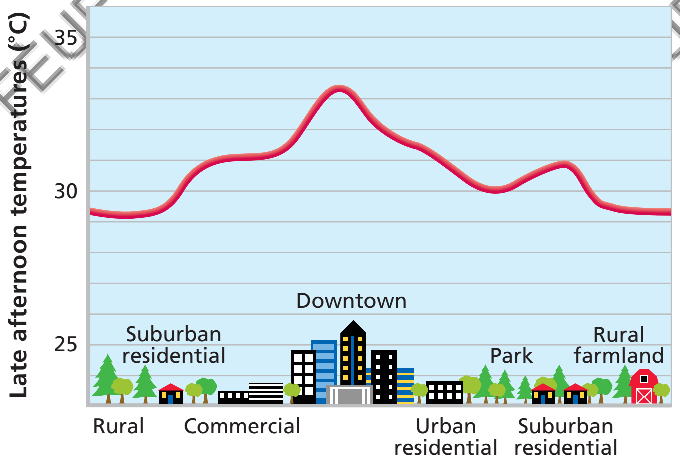


Figure 2 ▶ The less vegetation and more pavement and buildings an area has, the higher the temperatures in the area tend to be.

Local Climates

The climate of a small area is called a **microclimate.** Microclimates are influenced by density of vegetation, by elevation, and by proximity to large bodies of water. For example, in a city, pavement and buildings absorb and reradiate a lot of solar energy, which raises the temperature of the air above and creates a "heat island," as shown in **Figure 2.** As a result, the average temperature may be a few degrees higher in the city than it is in surrounding rural areas. In contrast, vegetation in rural areas does not reradiate as much energy, so temperatures in those areas are lower.

microclimate the climate of a small area

Effects of Elevation

Elevation also may affect local climates. As elevation increases, temperature decreases and the climate changes. For example, the *highland climate* is characterized by large variation in temperatures and precipitation over short distances because of changes in elevation. Highland climates are commonly located in mountainous regions—even in tropical areas.

Effects of Large Bodies of Water

Large bodies of water, such as lakes, influence local climates. The water absorbs and releases heat slower than land does. Thus, the water moderates the temperature of the nearby land. Large bodies of water can also increase precipitation. Therefore, microclimates near large bodies of water have a smaller range of temperatures and higher annual precipitation than other locations at the same latitude do.

Section 2 Review

1. **Identify** the three types of climate zones.
2. **Describe** the three types of tropical climates.
3. **Describe** the five types of middle-latitude climates.
4. **Describe** the three types of polar climates.
5. **Identify** three factors that influence microclimates.
6. **Explain** why city climates may differ from rural climates.

CRITICAL THINKING

7. **Making Inferences** What would happen to the temperature of a rural location if the vegetation were replaced with a parking lot?
8. **Compare and Contrast** Compare latitude lines with the boundaries of major climate zones. Why do they align in some regions but not in others?

CONCEPT MAPPING

9. Use the following terms to create a concept map: *tropical climate, subarctic, tundra, steppe, polar icecap, mediterranean, middle-latitude climate, rain forest, savanna, desert,* and *polar climate.*

ENVIRONMENTAL CONNECTION

Section 3 Climate Change

When discussing changes in climate, scientists must answer two questions. First, is the climate really changing, or are year-to-year changes just natural variation? Second, if the climate is changing, what is the cause? **Climatologists** are scientists who try to answer these questions by gathering data to study and compare past and present climates.

OBJECTIVES

- **Compare** four methods used to study climate change.
- **Describe** four factors that may cause climate change.
- **Identify** potential impacts of climate change.
- **Identify** ways that humans can minimize their effect on climate change.

KEY TERMS

climatologist
global warming

Studying Climate Change

Climatologists look to past climates to find patterns in the changes that occur. Identifying those patterns allows the scientists to make predictions about future climates. Climatologists use a variety of techniques to reconstruct changes in climate.

Collecting Climate Data

Today, scientists use thousands of weather stations around the world to measure recent precipitation and temperature changes. However, when trying to learn about factors that influence climate change, scientists need to study the evidence left by past climates. This evidence can be left in the remains of plants and animals from earlier time periods. For example, *fossils* of a plant or animal may show adaptations to a particular environment that can reveal clues about the environment's climate. Even polar icecaps contain evidence of past climates. By studying the concentration of gases in *ice cores,* scientists can learn about the gas composition of the atmosphere thousands of years ago. **Table 1** describes methods used to study past climates.

climatologist a scientist who gathers data to study and compare past and present climates and to predict future climate change

Table 1 ▼

Methods of Studying Past Climates			
Method	**What is measured**	**What is indicated**	**Length of time measured**
Ice cores	concentrations of gases in ice and meltwater	High levels of CO_2 indicate warmer climate; ice ages follow decreases in CO_2.	hundreds of thousands of years
Sea-floor sediment	concentration of ^{18}O in shells of microorganisms	High ^{18}O levels indicate cool water; lower ^{18}O levels indicate warm water.	hundreds of thousands of years
Fossils	pollen types, leaf shapes, and animal body adaptations	Flower pollens and broad leaves indicate warm climates; evergreen pollens and small, waxy leaves indicate cool climates. Animal fossils show adaptations to climate changes.	millions of years
Tree rings	ring width	Thin rings indicate cool weather and less precipitation.	hundreds to thousands of years

Figure 1 ▶ Scientists need to use powerful computers to process the amount of data required to study climates.

Modeling Climates

Because so many factors influence climate, studying climate change is a complicated process. Currently, scientists use computers to create models to study climate, as shown in **Figure 1.** The models incorporate millions of pieces of data and help sort the complex sets of variables that influence climate. These models are called *general circulation models,* or GCMs. GCMs simulate changes in one variable when other variables are unchanged. For example, if the sulfur dioxide level is raised in a particular model, the model indicates a decrease in incoming solar radiation because sulfur dioxide reflects sunlight.

Climate models predict many factors of climate, including temperature, precipitation, wind patterns, and sea-level changes. These computer models are complex because they model interactions between oceans, wind, land, clouds, and vegetation. As computers become more powerful, computer-generated climate models will become more accurate and will help scientists better understand climate change.

Reading Check **Why do scientists use computers to model climate? (See the Appendix for answers to Reading Checks.)**

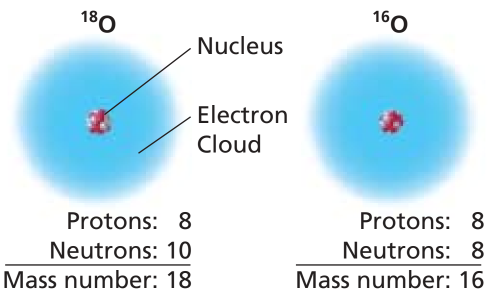
Connection to CHEMISTRY

Oxygen Isotopes

By studying the shells of certain marine organisms, scientists have found evidence that the oceans were much warmer during the Jurassic period than they are today. Marine shells form differently depending on the temperature of the ocean, because the concentration of oxygen isotopes in the marine shells depends on the temperature of the water.

Isotopes are atoms of the same element that have a different number of neutrons. All elements are made up of atoms that contain protons, electrons, and neutrons. Isotopes of the same element have the same number of protons and electrons, but have a different number of neutrons.

Because isotopes have a different number of neutrons, they have different mass numbers. For example, oxygen's most common isotope has a mass number of 16 and is written as ^{16}O. A less common isotope of oxygen is ^{18}O.



Marine shells contain both isotopes ^{16}O and ^{18}O. When the temperature of the sea water increases, the concentration of ^{18}O decreases and the concentration of ^{16}O increases. Scientists study the fossils of marine shells from different time periods to determine the concentration of each oxygen isotope in the marine shells. Upon determining the concentrations, scientists can predict the temperature of the oceans during the time period in which the shells formed.

Potential Causes of Climate Change

By studying computer-generated climate models, scientists have determined several potential causes of climate change. Factors that might cause climate change include the movement of tectonic plates, changes in the Earth's orbit, human activity, and atmospheric changes.

Graphic Organizer **Cause-and-Effect Map**

Create the Graphic Organizer entitled "Cause-and-Effect Map" described in the Skills Handbook section of the Appendix. Label the effect with "Climate change." Then, fill in the map with causes of climate change and details about the causes and effects.

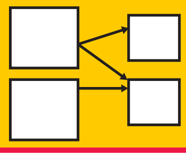


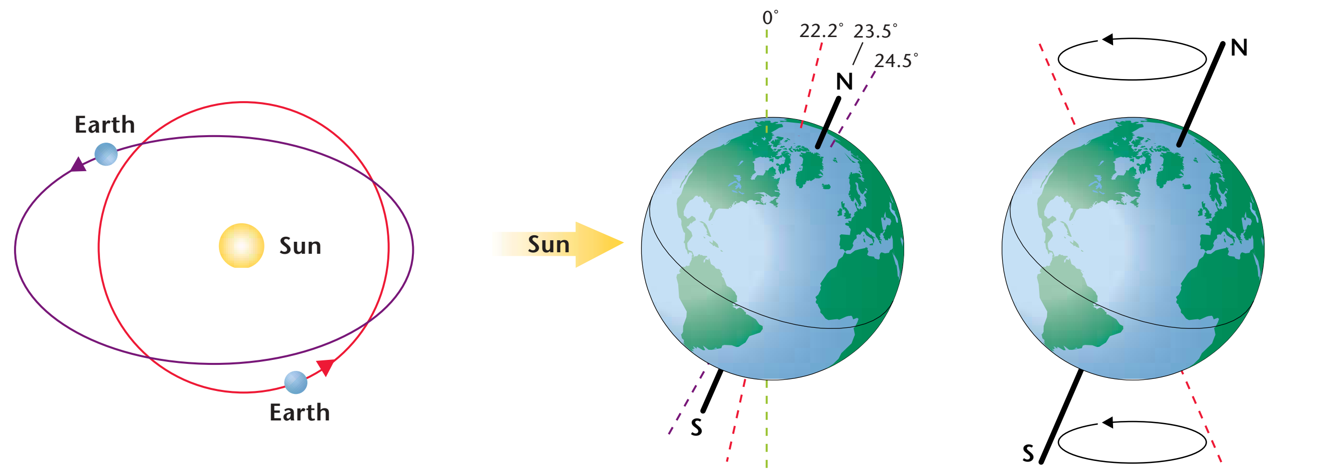
Plate Tectonics

The movement of continents over millions of years caused by tectonic plate motion may affect climate changes. The changing position of the continents changes wind flow and ocean currents around the globe. These changes affect the temperature and precipitation patterns of the continents and oceans. Thus, the climate of any particular continent is not the same as it was millions of years ago.

Orbital Changes

Changes in the shape of Earth's orbit, changes in Earth's tilt, and the wobble of Earth on its axis can lead to climate changes, as shown in **Figure 2.** The combination of these factors is described by the *Milankovitch theory*. Each change of motion has a different effect on climate. Variation in the shape of Earth's orbit, from elliptical to circular, affects Earth's distance from the sun. Earth's distance from the sun affects the temperature of Earth and therefore affects the climate. Decreasing tilt decreases temperature differences between seasons. The wobble of Earth on its axis changes the direction of Earth's tilt and can reverse the seasons. These changes occur in cycles of 21,000 to 100,000 years.

Figure 2 ▶ Earth's Orbital Changes



Eccentricity Earth encounters more variation in the energy that it receives from the sun when Earth's orbit is elongated than it does when Earth's orbit is circular.

Tilt The tilt of Earth's axis varies between 22.2° and 24.5°. The greater the tilt angle is, the more solar energy the poles receive.

Precession The wobble of Earth's axis affects the amount of solar radiation that reaches different parts of Earth's surface at different times of the year.

Figure 3 ▶ Most deforestation in Brazil is caused by farmers who clear the land for planting crops.

Human Activity

Many scientists think that human activity affects climate. Pollution from transportation and industry releases carbon dioxide, CO_2, into the atmosphere. Increases in CO_2 concentrations may lead to global warming, an increase in temperatures around Earth. CO_2 is also released into the atmosphere when trees are burned to provide land for agriculture and urban development. Because vegetation uses CO_2 to make food, deforestation, as shown in **Figure 3**, also affects one of the natural ways of removing CO_2 from the atmosphere. As scientists continue to study climate, they will learn more about how human activity affects climate and about how changes in climate may affect us.

Volcanic Activity

Large volcanic eruptions can influence climates around the world. Sulfur and ash from eruptions can decrease temperatures by reflecting sunlight back into space. These changes last from a few weeks to several years and depend on the strength and duration of the eruption.

QuickLAB 15 min

Hot Stuff

Procedure

1. In mid-afternoon, use a **thermometer** to measure the air temperature over a grassy field or other vegetated area. Make sure to shield the thermometer from direct sunlight.
2. Measure the air temperature over a parking lot. Take the measurement at the same height above the surface as the height of the measurement of the vegetated area. Again, make sure the thermometer is not directly in the sunlight.

Analysis

1. How did the results differ for each location?
2. How would you explain the difference in the results?
3. What suggestion for how to keep cooling costs low would you give to someone who is building a new store?

Potential Impacts of Climate Change

Scientists are concerned about climate changes because of the potential impacts of these changes. Earth's atmosphere, oceans, and land are all connected, and each influences both local and global climates. Changes in the climate of one area can affect climates around the world. Climate change affects not only humans but also plants and animals. Even short-term changes in the climate may lead to long-lasting effects that may make the survival of life on Earth more difficult for both humans and other species. Some of these potential climate changes include global warming, sea-level changes, and changes in precipitation.

Reading Check **What things are influenced by climate change? (See the Appendix for answers to Reading Checks.)**

Global Warming

Global temperatures have increased approximately 1°C over the last 100 years. Researchers are trying to determine if this increase is a natural variation or the result of human activities, such as deforestation and pollution. A gradual increase in average global temperatures is called **global warming.** This process may result from an increase in the concentration of greenhouse gases, such as CO_2, in the atmosphere.

An increase in global temperature can lead to an increase in evaporation. Increased evaporation could cause some areas to become drier than they are now. Some plants and animals would not be able to live in these drier conditions. An increase in evaporation in other areas could cause crops to suffer damage. However, an increase in temperatures due to global warming might improve conditions for crops in colder, northern regions.

An increase in global temperatures could also cause ice at the poles to melt. If a significant amount of ice melts, sea levels around the world could rise. This rise in sea levels would cause flooding around coastlines, where many cities are located.

global warming a gradual increase in the average global temperature that is due to a higher concentration of gases such as carbon dioxide in the atmosphere

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Topic: Global Warming

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Sea-Level Changes

Using computer models, some scientists have predicted an increase in global temperature of 2°C to 4°C during this century. An increase of only a few degrees worldwide could melt the polar icecaps and raise sea level by adding water to the oceans. On a shoreline that has a gentle slope, the shoreline could shift inland many miles, as shown in **Figure 4.** Many coastal inhabitants would be displaced, and freshwater and agricultural land resources would be diminished. Because approximately 50% of the world population lives near coastlines, this sea-level rise would have devastating effects.

Figure 4 ▶ As sea level rises, shorelines could shift inland many miles. ***Which two states would lose the most area if sea level were to rise by 3 m?***

Figure 5 ▶ People from the Wangari Maathai Green Belt Movement in Kenya, Africa, prepare seedlings for planting.

What Humans Can Do

Many countries are working together to reduce the potential effects of global warming. Treaties and laws have been passed to reduce pollution. Industrial practices are being monitored and changed. Even community projects to reforest areas, such as the one shown in **Figure 5,** have been developed on a local level.

Individual Efforts

Each individual person can also help to reduce CO_2 concentrations in the atmosphere that are caused by pollution. Pollution is caused mostly by the burning of fossil fuels, such as running automobiles and using electricity. Therefore, humans can have a significant effect on pollution rates by turning lights off when they are not in use, by turning down the heat in winter, and by reducing air conditioner use in the summer. Recycling is also helpful because less energy is needed to recycle some products than to create them.

Transportation Solutions

Using public transportation and driving fuel-efficient vehicles also help release less CO_2 into the atmosphere. All vehicles burn fuel more efficiently when they are properly tuned and the tires are properly inflated. Driving at a consistent speed also allows a vehicle to burn fuel efficiently. Car manufacturers have been developing cars that are more fuel efficient. For example, *hybrid cars* use both gasoline and electricity. These cars release less CO_2 into the atmosphere from burning fuel than other cars do.

Section 3 Review

1. **Compare** four methods that climatologists use to study climate.
2. **Identify** four factors that may cause climate change.
3. **Describe** how orbital changes may affect climate.
4. **Explain** how changes in CO_2 concentrations affect global temperatures.
5. **Explain** one potential negative impact of global warming.
6. **Identify** two ways that countries can work together to reduce the potential effects of global warming.
7. **Identify** four ways that an individual can reduce the potential effects of global warming.

CRITICAL THINKING

8. **Making Predictions** How would the melting of small icebergs affect sea level? Explain your answer.
9. **Evaluating Models** Can short-term climate changes be explained by using the cycles described by the Milankovitch theory? Explain your answer.

CONCEPT MAPPING

10. Use the following terms to create a concept map: *climatologist, general circulation models, global warming, ice cores, tree rings, fossils,* and *isotopes.*

Chapter 25 Highlights

Sections

1 Factors That Affect Climate

Key Terms

climate, 631
specific heat, 634
El Niño, 635
monsoon, 635

Key Concepts

- The climate of a region is described by the region's temperature and precipitation.
- Latitude affects climate by determining the intensity of solar energy received by an area.
- The rates at which land and water are heated affect climate.
- Topography affects climate by causing temperature variations due to elevation and by creating rain shadows.

2 Climate Zones

tropical climate, 637
middle-latitude climate, 638
polar climate, 639
microclimate, 640

- Tropical subclimates are located near the equator and include tropical rain-forest, tropical desert, and savanna climates.
- Middle-latitude climates include marine west coast, steppe, humid continental, humid subtropical, and mediterranean climates.
- Polar climates include subarctic, tundra, and polar icecap climates.
- Microclimates are influenced by large bodies of water, by elevation, and by vegetation and urban development.

3 Climate Change

climatologist, 641
global warming, 645

- By using ice cores, sea-floor sediment, fossils, and tree rings, scientists have been able to study past climates.
- Computer-generated climate models help scientists predict possible consequences of changing certain variables in the climate system.
- Natural processes and human activities may be causing changes in Earth's climate, including global warming.

Chapter 25 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *specific heat*
2. *microclimate*
3. *climatologist*

For each pair of terms, explain how the meanings of the terms differ.

4. *climate* and *microclimate*
5. *El Niño* and *monsoon*
6. *tropical climate* and *polar climate*

Understanding Key Concepts

7. At the equator, the sun's rays always strike Earth
   a. at a low angle.
   b. at nearly a 90° angle.
   c. 18 hours each day.
   d. no more than 8 hours each day.

8. Which of the following is *not* used as evidence of past climates?
   a. ice cores
   b. general circulation models
   c. tree rings
   d. fossils

9. Water cools
   a. more slowly than land does.
   b. more quickly than land does.
   c. only during evaporation.
   d. during global warming.

10. Ocean currents influence temperature by
    a. eroding shorelines.
    b. heating or cooling the air.
    c. washing warm, dry sediments out to sea.
    d. dispersing the rays of the sun.

11. Winds that blow in opposite directions in different seasons because of the differential heating of the land and the oceans are called
    a. chinooks.
    b. foehn.
    c. monsoons.
    d. El Niño.

12. When a moving air mass encounters a mountain range, the air mass
    a. stops moving.
    b. slows and sinks.
    c. rises and cools.
    d. reverses its direction.

13. In regions that have a mediterranean climate, almost all of the yearly precipitation falls
    a. during monsoons.
    b. in the summer.
    c. in the winter.
    d. during hurricanes.

14. The climate that has the largest annual temperature range is the
    a. subarctic climate.
    b. middle-latitude desert climate.
    c. mediterranean climate.
    d. humid continental climate.

15. The pavement and buildings in cities affect the local climate by
    a. decreasing the temperature.
    b. increasing the temperature.
    c. increasing the precipitation.
    d. decreasing the precipitation.

Short Answer

16. Describe the Milankovitch theory, including how it may explain some climate changes.

17. What are the possible effects of global warming?

18. Compare marine west coast and humid continental climates.

Critical Thinking

19. Making Predictions Describe how the climate in California might be affected if all of the trees in California were cut down.

20. Making Inferences Explain why the vegetation in areas that have a tundra climate is sparse even though these areas receive enough precipitation to support plant life.

21. Analyzing Ideas Explain why climates cannot be classified only by latitude.

22. Predicting Consequences How would global climate be affected if Earth were not tilted on its axis? Explain your reasoning.

Concept Mapping

23. Use the following terms to create a concept map: *fossil, ice cores, climate, polar climate, climatologist, steppe, temperature range, tropical climate, middle-latitude climate,* and *savanna*.

Math Skills

24. Using Equations Temperature generally decreases about 6.5°C for every kilometer above sea level. If T_N = temperature at new altitude, a = altitude in kilometers, and T_I = the initial temperature at sea level, what equation can be used to find the temperature at a given altitude?

25. Making Calculations From 1970 to 1997, nitrous oxide, NO_2, emissions increased from about 18.7 million to about 20.8 million tons per year. By what percentage did NO_2 emissions increase from 1970 to 1997?

Writing Skills

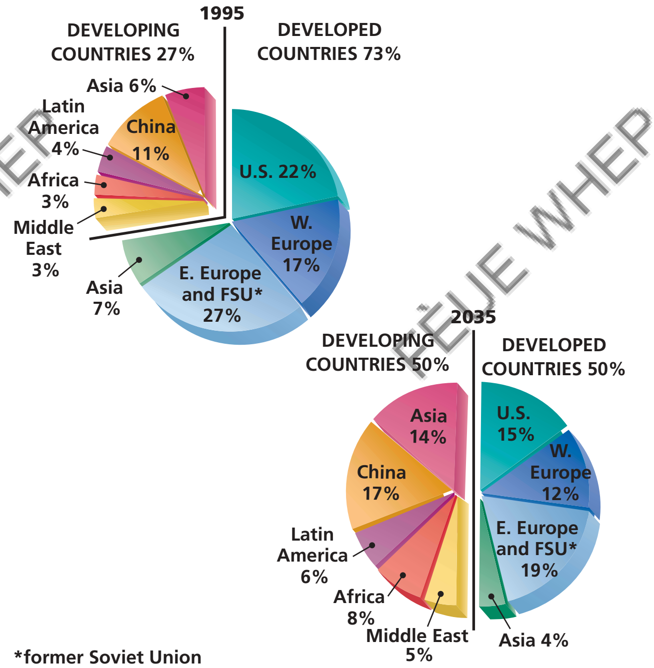
26. Researching Topics Research greenhouse gases to determine how they are produced. Then, write a brief essay that outlines how they can be reduced.

27. Communicating Main Ideas Imagine that you are going to build a vacation house. Research three locations where you would like to build your house, and outline the climate features that would make each location ideal for your vacation home.

Interpreting Graphics

The pie graphs below show world emissions of carbon dioxide, CO_2, in 1995 and predict emissions in 2035. Use these graphs to answer the questions that follow.

Total World Emissions of Carbon Dioxide



28. In 1995, which country or region emitted the most CO_2? Which emitted the least CO_2?

29. What percentage of the total CO_2 was emitted by developing countries in 1995?

30. Why do you think researchers predict that CO_2 emissions by developing countries will equal that of developed countries by 2035?

Chapter 25 Standardized Test Prep

Understanding Concepts

***Directions (1–4):* For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 Which statement best compares how land and water are heated by solar energy?
A. Water heats up faster and to a higher temperature than land does.
B. Land heats up faster and to a higher temperature than water does.
C. Water heats up more slowly but reaches a higher temperature than land does.
D. Land heats up more slowly and reaches a lower temperature than water does.

2 Which of the following statements best describes the El Niño–Southern Oscillation?
F. a change in global wind patterns that occurs in the Southern Hemisphere
G. a warming of surface waters in the eastern Pacific due to the effects of changing wind patterns on ocean currents near the equator
H. a cooling of surface waters in the eastern Pacific due to the effects of changing wind patterns on ocean currents near the equator
I. a global wind and precipitation belt between 20°N and 30°N latitude

3 A seasonal wind that blows toward the land in the summer and brings heavy rains is called a
A. trade wind
B. jet stream
C. doldrum
D. monsoon

4 In samples of atmospheric gases taken from ice cores, high levels of carbon dioxide indicate that the sample is from a time period that had
F. a warm climate
G. a cool climate
H. high amounts of precipitation
I. low amounts of precipitation

***Directions (5–6):* For *each* question, write a short response.**

5 What is the term for the area around a mountain that receives warm, dry winds?

6 What is the term for the average weather in an area over a long period of time?

Reading Skills

***Directions (7–9):* Read the passage below. Then, answer the questions.**

The Greenhouse Effect

The greenhouse effect is Earth's natural heating process, in which gases in the atmosphere trap thermal energy. Earth's atmosphere acts like the glass windows of a car. Imagine that it is a hot day and that you are about to get inside a car. You immediately notice that it feels hotter inside the car than it does outside the car.

Many scientists hypothesize that the rise in global temperatures is due to an increase in carbon dioxide that is produced as a result of human activity. Most evidence indicates that the increase in carbon dioxide is caused by the burning of fossil fuels that release carbon dioxide into the atmosphere. Fossil fuels are organic compounds that are formed from the buried remains of ancient plants and animals. These fuels are used by humans for many things such as heating homes and providing fuel for automobiles.

7 Based on the passage, which of the following statements is not true?
A. The atmosphere of Earth traps thermal heat in a similar manner to the way a car window traps heat.
B. The greenhouse effect is a natural heating process for Earth.
C. Earth absorbs sunlight and reradiates it as carbon dioxide.
D. Human activity is the one producer of the greenhouse gas carbon dioxide.

8 Which of the following statements can be inferred from the information in the passage?
F. The greenhouse effect is responsible for an increase in the use of fossil fuels by humans.
G. Humans created the greenhouse effect by burning coal for industrial uses.
H. Human activity is the only producer of gases that create the greenhouse effect.
I. Human activity may play a role in amplifying the natural process of the greenhouse effect.

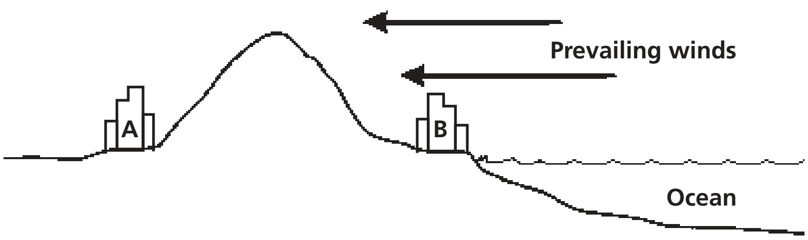
9 Name some fossil fuels that are contributors to the production of carbon dioxide?

Interpreting Graphics

***Directions (10–13):* For *each* question below, record the correct answer on a separate sheet of paper.**

The diagram shows the locations of two cities at the same latitude. Use this map to answer questions 10 and 11.

Two Cities Separated by Coastal Mountains

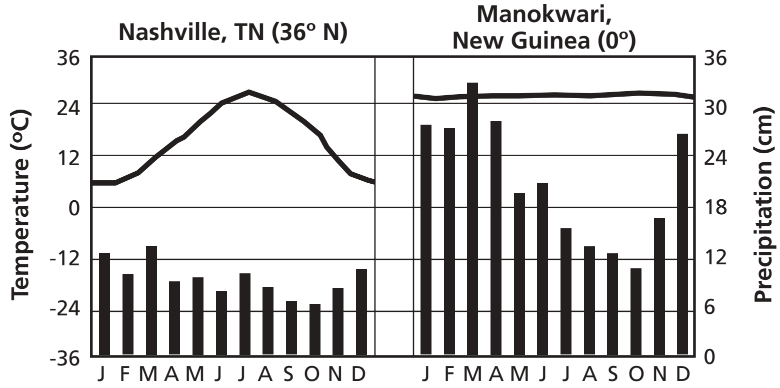


10 Which city is most likely to have the largest yearly temperature range?
A. City A would likely have the largest yearly temperature range.
B. City B would likely have the largest yearly temperature range.
C. Both cities would likely have the same temperature range.
D. There is not enough information to answer the question.

11 Which city is most likely to have a dry climate? Explain what would cause this city's climate to be drier than the other city's climate.

The climatograms below summarize average monthly precipitation and temperature data measured in two locations over a period of one year. Use these climatograms to answer questions 12 and 13.

Climatograms for Two Cities



12 Which month shows the most rainfall for both climates in the climatograms?
F. March
G. June
H. September
I. December

13 Based on the data in the climatograms, write a description of the climate found in each location and the type of vegetation that is likely to occur as a result of the climate in each location.

Test TIP

Read all of the information, including the heads, in a table or chart before answering the questions that refer to it.

Chapter 25

Inquiry Lab

Using Scientific Methods

Objectives

- **Determine** whether land or water absorbs heat faster.
- **Explain** how the properties of land and water affect climate.

Materials

container (2)
heat lamp
meterstick
soil
thermometer, Celsius (2)
water

Safety

Factors That Affect Climate

Many factors affect climate. One of the most significant factors that influence climate is the distribution of land and water. Because land and water absorb and release heat energy differently, they affect the atmosphere differently. In turn, the differences between land and water affect the climate. In this lab, you will explore how the properties of land and water affect climate.

ASK A QUESTION

1. How do the properties of land and water affect climate?

FORM A HYPOTHESIS

2. On a separate piece of paper, write a hypothesis that is a possible answer to the question above.

TEST THE HYPOTHESIS

3. Fill one container with soil and the other with water. Place both containers on a flat surface next to each other.
4. Place the thermometer in the soil, as shown below, and record the temperature.

Step 5

5 Place the second thermometer in the container of water, as shown in the illustration on the previous page. The bulbs of both thermometers should be placed so that they are covered by no more than 0.5 cm of water or soil.

6 Place the heat lamp 25 cm above both containers. Turn on the heat lamp.

7 Create a data table like the one shown to the right. In the table, record the temperature of each sample at 1, 3, 5, and 10 min intervals.

Data Table

Time (min)	Temperature of soil (°C)	Temperature of water (°C)
1		
3		
5	DO NOT WRITE IN THIS BOOK	
10		
5 (after light off)		

8 Disconnect the lamp, and record the temperature of the soil and water after 5 min. **CAUTION** Be sure to let the heat lamp cool before storing it.

ANALYZE THE RESULTS

1 **Analyzing Data** Which substance absorbed more heat energy: water or soil?

2 **Analyzing Results** Which substance lost heat energy faster when the heat source was turned off: water or soil?

DRAW CONCLUSIONS

3 **Evaluating Conclusions** What conclusion can you draw about how land and water on Earth are heated by the sun?

4 **Analyzing Methods** Does this experiment describe how proximity to a body of water affects the temperature of a region? If so, explain your answer. If not, how could you test that variable?

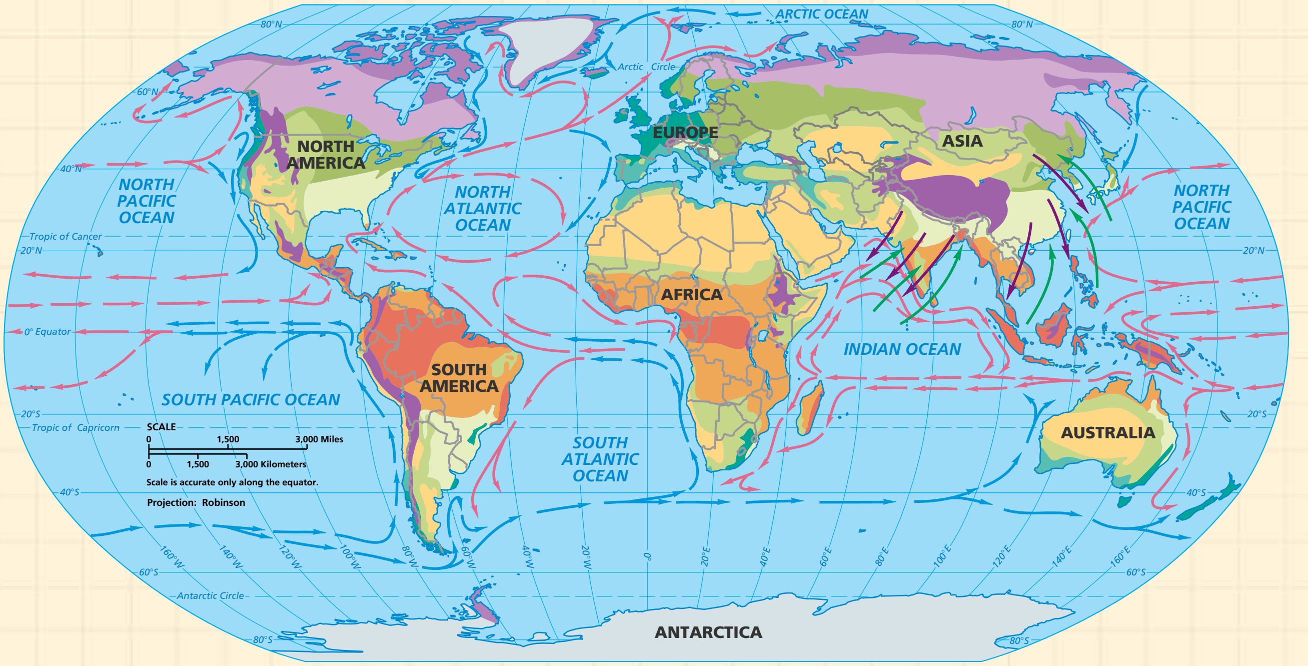
Extension

1 **Applying Ideas** Repeat this experiment, but modify the angle at which the light strikes the surface of the soil and the water. How do your results differ from the results of the original experiment? How does the angle of the light affect temperature change in water and soil?

8041

MAPS in Action

Climates of the World



Tropical Climates
- Rain forest
- Desert
- Savanna

Mid Latitude Climates
- Marine west coast
- Steppe
- Humid continental
- Humid subtropical
- Mediterranean

Polar Climates
- Subarctic
- Tundra
- Polar icecaps

- Highland

Monsoon Air Flow
- Wet monsoon
- Dry monsoon

Major World Ocean Currents
- Cool currents
- Warm currents

Map Skills Activity

This map shows the climate regions of Earth and the locations of warm and cold ocean currents. Use the map to answer the questions below.

1. **Analyzing Data** Estimate the latitude range for the desert climate of northern Africa.
2. **Making Comparisons** Why does the eastern coast of the United States have a different climate than the western coast does even though the coasts are at similar latitudes?
3. **Analyzing Ideas** If the ocean current that flows off the western coast of Australia were a warm current, how would this type of current affect the climate of western Australia?
4. **Using a Key** Identify the latitudes where monsoons are located.
5. **Evaluating Data** Explain why the western coast of South America is desert while the inland part of the continent at the same latitude is humid.

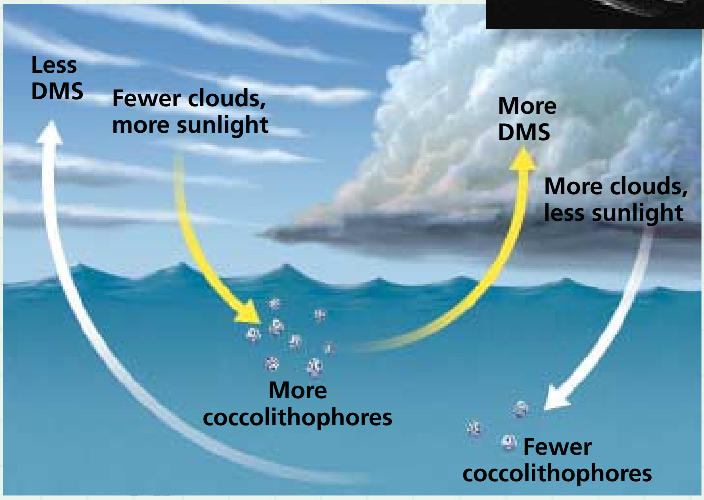
EYE on the Environment

Keeping Cool with Algae

Earth is constantly receiving energy from the sun. At the same time, Earth emits energy into space. By balancing these processes, Earth maintains its temperature. What keeps Earth from getting too hot or too cold? In seeking to answer this question, scientists look to microorganisms called *coccolithophores*.

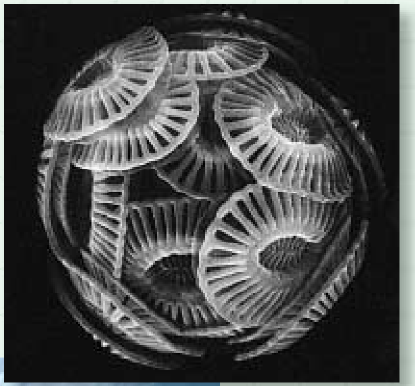
Disappearing Carbon Dioxide

Each year, humans release more than 6 billion tons of carbon dioxide, CO_2, but only about half of that amount can be detected in the atmosphere. Where does the rest of the CO_2 go? Much of it is absorbed by coccolithophores in the oceans. These tiny algae are the primary users of CO_2. They use CO_2 to build chalky disks made of calcium carbonate. By absorbing the CO_2, these algae have a significant impact on the greenhouse effect.



DMS and Sulfur Cycles

Coccolithophores also may affect the number of clouds that form. These algae absorb sulfur compounds from ocean water to produce dimethyl sulfide, or DMS, which is then released into the air. DMS causes water vapor to condense and form clouds. As more clouds form, sunlight is blocked and photosynthesis is reduced. The number of algae begins to decline. Less DMS is produced, and fewer clouds form. When more sunlight hits the ocean, more coccolithophores can grow, and the cycle continues.



▲ This tiny microorganism may help regulate the temperature of our planet.

Scientists think that this process may help serve as a natural thermostat for the entire planet.

Tough Puzzles to Solve

Scientists now have a better understanding of how coccolithophores affect the atmosphere. However, scientists do not know if this knowledge can be used to help regulate climates. If scientists could promote coccolithophore growth in the ocean, atmospheric CO_2 could be reduced and more clouds could be created. As a result, the planet would cool down. However, because scientists do not know how marine ecosystems would be affected, this plan would be risky. As research continues, scientists will probably learn more about how to apply this research.

Extension

1. **Making Inferences** Why would predicting the effects of artificially promoting coccolithophore growth be difficult?
2. **Understanding Relationships** Find out about other marine microorganisms. How are they important to other organisms in marine ecosystems?

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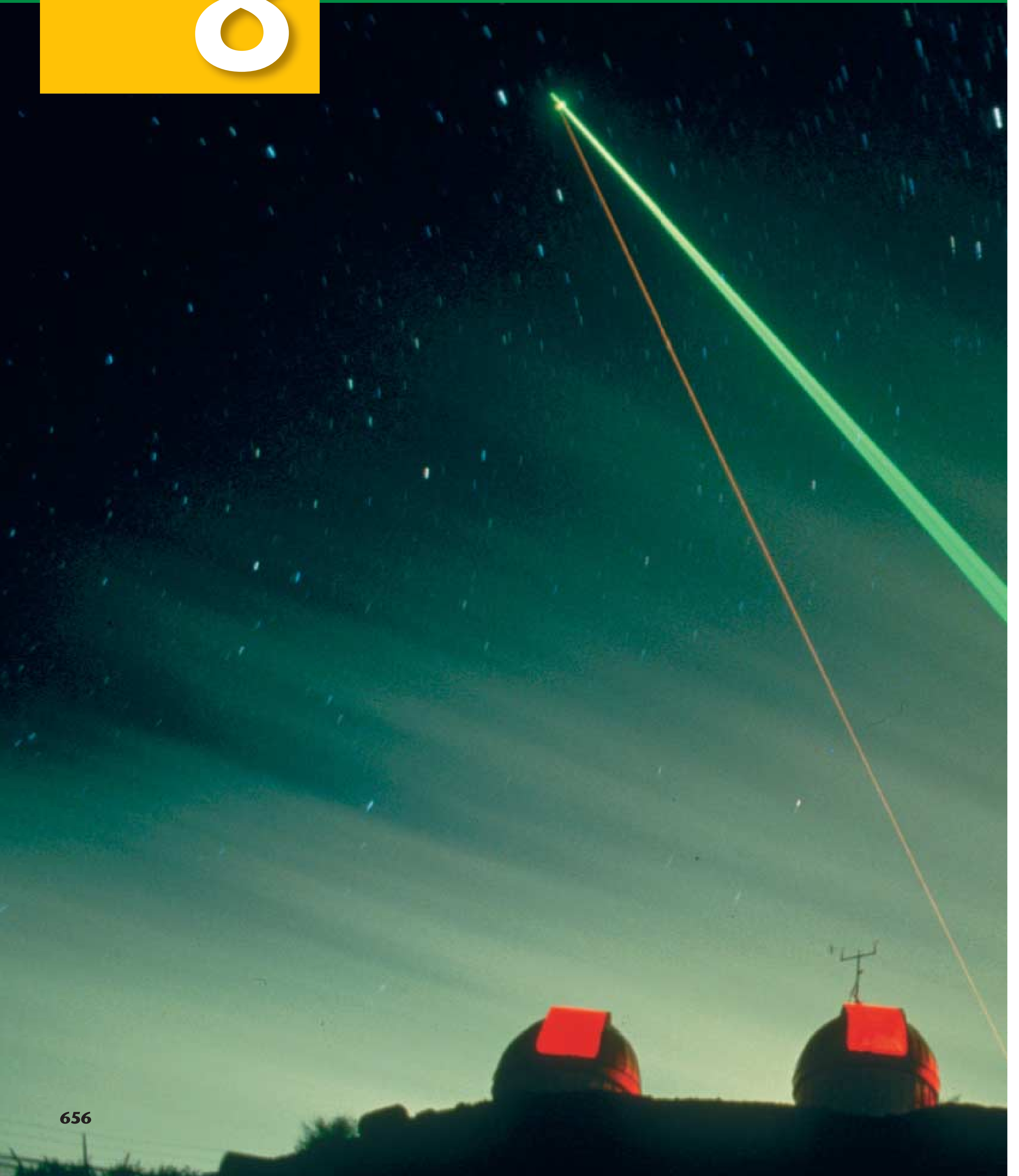
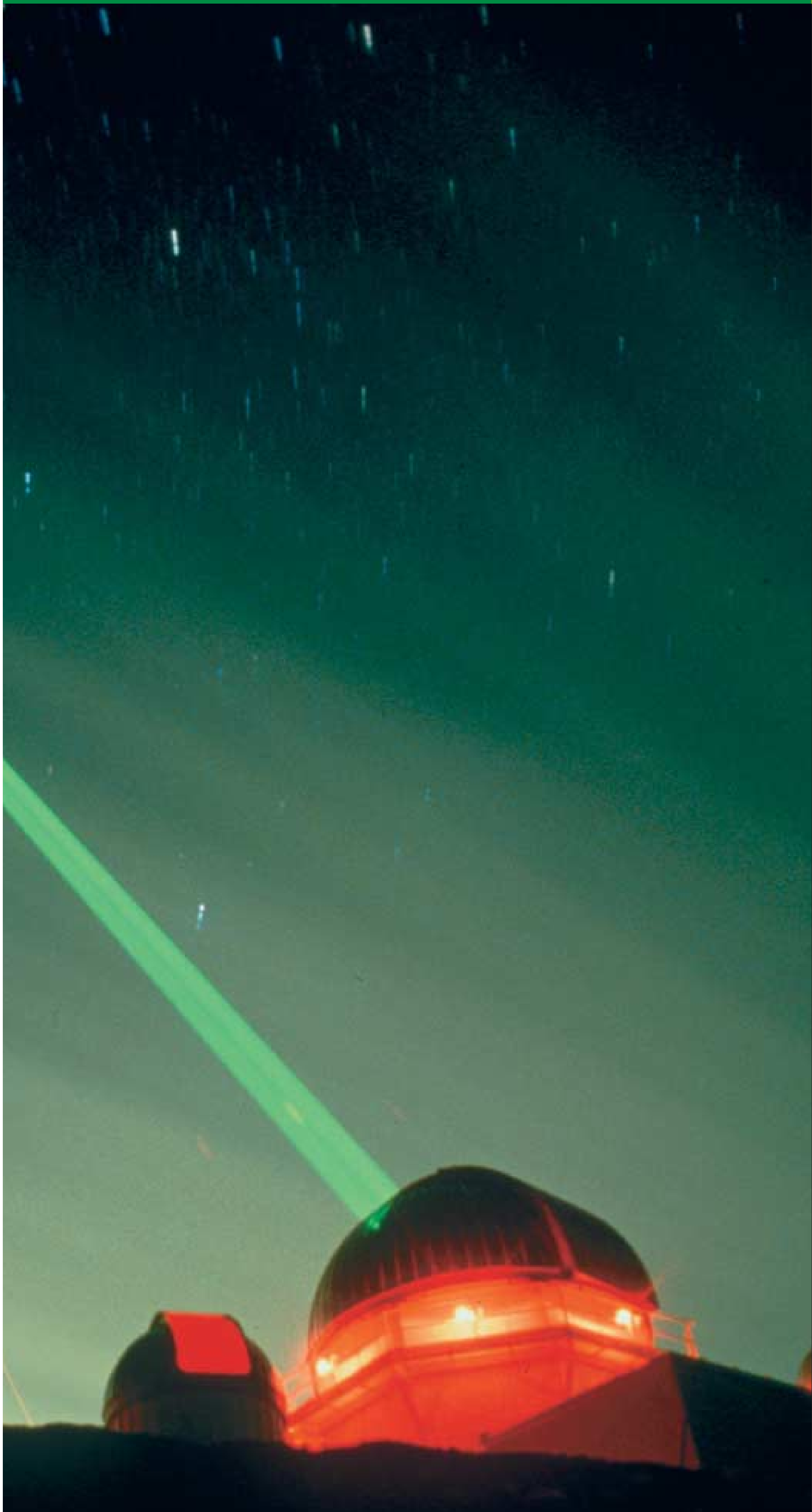
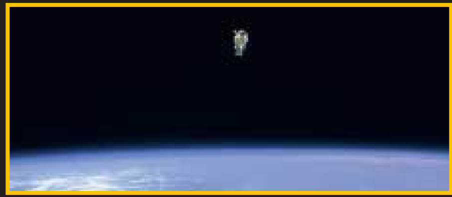
Unit 8 SPACE

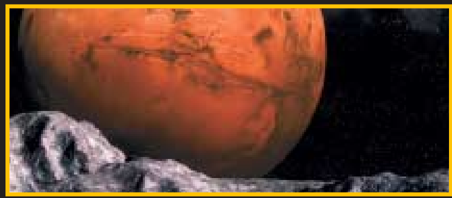


Unit 8 Outline





CHAPTER 26
Studying Space



CHAPTER 27
Planets of the Solar System

CHAPTER 28
Minor Bodies of the Solar System

CHAPTER 29
The Sun

CHAPTER 30
Stars, Galaxies, and the Universe

▶ The Starfire telescope in New Mexico provides clear images by using a laser to compensate for atmospheric turbulance.

Chapter 26 Studying Space

Sections

What You'll Learn

- How astronomers study the universe
- How different kinds of telescopes and spacecraft work
- How Earth moves and the consequences of that movement

Why It's Relevant

Understanding how scientists study space helps to explain the physical nature of the universe. Learning how Earth moves in space can help explain phenomena such as Earth's seasons.

PRE-READING ACTIVITY

FOLDNOTES

Two-Panel Flip Chart

Before you read this chapter, create the **FoldNote** entitled "Two-Panel Flip Chart" described in the Skills Handbook section of the Appendix. Label the flaps of the two-panel flip chart with "Tools of astronomy" and "Movements of Earth." As you read the chapter, write information you learn about each category under the appropriate flap.

▶ Astronaut Bruce McCandless II tests a backpack jet propelled by nitrogen that takes him 320 ft from the space shuttle. Equipment, such as the backpack, help scientists explore space.

Section 1 Viewing the Universe

People studied the sky long before the telescope was invented. For example, farmers observed changes in daylight throughout the year to track seasons and to predict floods and droughts. Sailors focused on the stars to navigate through unknown territory. Today, most interest in studying the sky comes from a curiosity to discover what lies within the universe. This scientific study of the universe is called **astronomy.** Scientists who study the universe are called *astronomers*.

OBJECTIVES

- **Describe** characteristics of the universe in terms of time, distance, and organization.
- **Identify** the visible and nonvisible parts of the electromagnetic spectrum.
- **Compare** refracting telescopes and reflecting telescopes.
- **Explain** how telescopes for nonvisible electromagnetic radiation differ from light telescopes.

KEY TERMS

astronomy
galaxy
astronomical unit
electromagnetic spectrum
telescope
refracting telescope
reflecting telescope

astronomy the scientific study of the universe

The Value of Astronomy

In the process of observing the universe, astronomers have made exciting discoveries, such as new planets, stars, black holes, and nebulas, such as the one shown in **Figure 1.** By studying these objects, astronomers have been able to learn more about the origin of Earth and the processes involved in the formation of our solar system.

Studying the universe is also important for the potential benefits to humans. For example, studies of how stars shine may one day lead to improved or new energy sources on Earth. Astronomers may also learn how to protect us from potential catastrophes, such as collisions between asteroids and Earth. Because of these and other contributions, astronomical research is supported by federal agencies, such as the National Science Foundation and NASA. Private foundations and industry also fund research in astronomy.

Figure 1 ▶ A nebula is a large cloud of gas and dust in space. This nebula is called the Eskimo nebula. It formed as a result of an explosion on the surface of the central star. By studying nebulas, scientists may learn if our sun will ever reach this state.

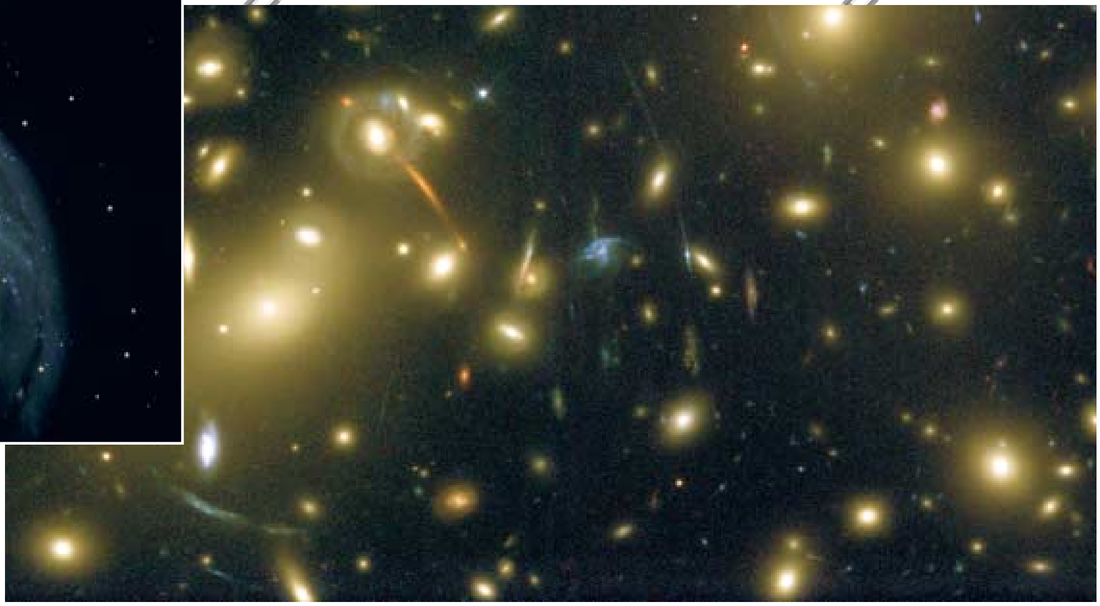
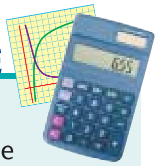


Figure 2 ▶ The Whirlpool galaxy, M51 (above), is 28 million light-years from the Milky Way. Abell 1689 (right) is one of the most massive galaxy clusters known.

MATHPRACTICE



Astronomical Unit
An astronomical unit is the average distance between the sun and Earth, or about 150 million km. Venus orbits the sun at a distance of 0.7 AU. Venus is how many kilometers from the sun?

galaxy a collection of stars, dust, and gas bound together by gravity

astronomical unit the average distance between the Earth and the sun; approximately 150 million kilometers (symbol, AU)

Characteristics of the Universe

The study of the origin, properties, processes, and evolution of the universe is called *cosmology*. Most astronomers agree that the universe began about 14 billion years ago in one giant explosion, called the *big bang*. Since that time, the universe has continued to expand. The universe is very large, and the objects within it are extremely far apart. Telescopes are used to study some distant objects. However, astronomers also commonly use computer models to study the universe.

Organization of the Universe

The nearest part of the universe to Earth is our solar system. The solar system includes the sun, Earth, the other planets, and many smaller objects such as asteroids and comets. The solar system is part of a **galaxy,** which is a large collection of stars, dust, and gas bound together by gravity. The galaxy in which the solar system resides is called the *Milky Way galaxy*. Beyond the Milky Way galaxy, there are millions of other galaxies, a few of which are shown in **Figure 2.**

Measuring Distances in the Universe

Because the universe is so large, the units of measurement used on Earth are too small to represent the distance between objects in space. To measure distances in the solar system, astronomers often use astronomical units. An **astronomical unit** (symbol, AU) is the average distance between Earth and the sun, which is 149,597,870.66 km or approximately 150 million km.

Astronomers also use the speed of light to measure distance. Light travels at 300,000,000 m/s. In one year, light travels 9.4607×10^{12} km. This distance is known as a *light-year*. Aside from the sun, the closest star to Earth is 4.2 light-years away.

Observing Space

Light enables us to see the world around us and to make observations. When astronomers look at the night sky, they see stars and other objects in space because of the light these objects emit. Planets, however, do not emit light. They reflect the light from stars. However, this light is only a small amount of energy that comes from these objects. By studying the other forms of energy, astronomers are able to learn more about the universe.

Electromagnetic Spectrum

Visible light is part of a spectrum of energy called the electromagnetic spectrum. The **electromagnetic spectrum** is all of the wavelengths of electromagnetic radiation. Light, radio waves, and X rays are all examples of electromagnetic radiation. The radiation is composed of traveling waves of electric and magnetic fields that oscillate at fixed frequencies and wavelengths.

electromagnetic spectrum all of the frequencies or wavelengths of electromagnetic radiation

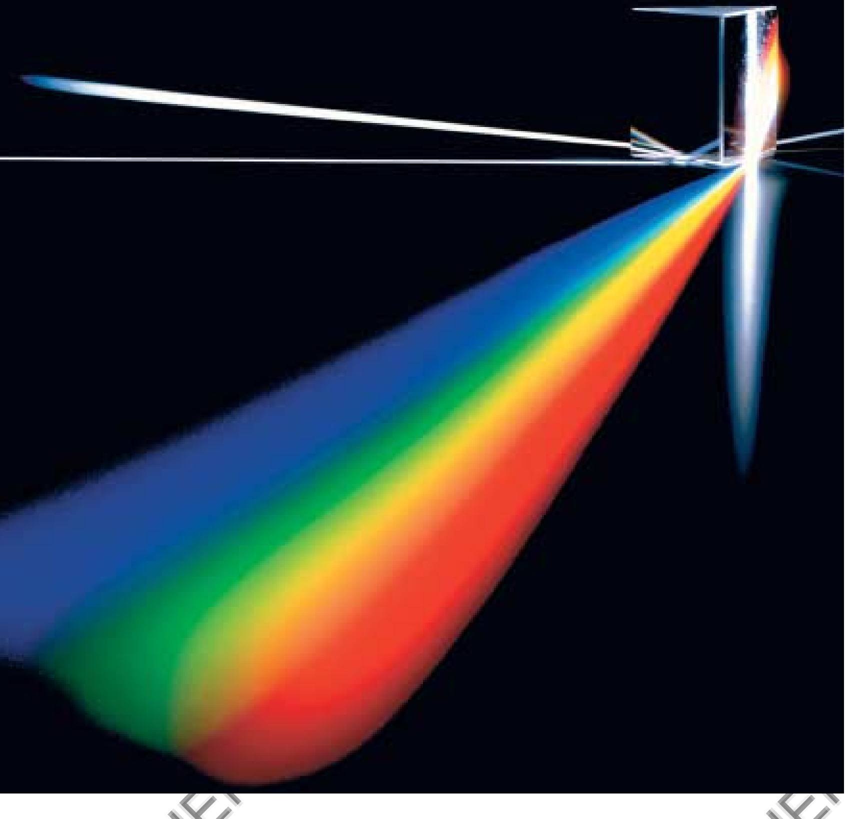
Visible Electromagnetic Radiation

The human eye can see only radiation of wavelengths in the visible light range of the spectrum. When white light passes through a prism, the light is broken into a continuous set of colors, as shown in **Figure 3.** Every rainbow formed in the sky and any color spectrum formed by a prism will always have the same colors in the same order. The different colors result because each color of light has a characteristic wavelength. Though all light travels at the same speed, different colors of light have different wavelengths. For example, the shortest wavelengths of light are blue and violet, while the longest wavelengths of light are orange and red.

Electromagnetic radiation that has wavelengths that are shorter than the wavelengths of violet light or longer than the wavelengths of red light cannot be seen by humans. But these wavelengths can be detected by instruments that are designed to detect electromagnetic radiation that cannot be seen by humans. These invisible wavelengths include infrared waves, microwaves, radio waves, ultraviolet rays, X rays, and gamma rays.

Reading Check **Which type of electromagnetic radiation can be seen by humans? (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ Visible light is broken into different colors because each color has a different wavelength. These colors can be seen when visible light is passed through a prism.



Invisible Electromagnetic Radiation

If you place a thermometer in any wavelength of the visible spectrum, the temperature reading on the thermometer will increase. In 1852, a scientist named Sir Frederick William Herschel moved the thermometer beyond the red end of the visible spectrum. Even though he could not see any light on the thermometer, the temperature reading on the thermometer increased. He had discovered *infrared,* which means “below the red.” Infrared is electromagnetic radiation that has waves that are longer than waves of visible light. Later, other scientists discovered radio waves, which have even longer wavelengths than infrared waves do.

The shortest wavelengths of visible light, which are shorter than the wavelengths of violet light, are the ultraviolet wavelengths. *Ultraviolet* means “beyond the violet.” The X-ray wavelengths are shorter than the ultraviolet wavelengths are. The shortest wavelengths are the gamma ray wavelengths.

Telescopes

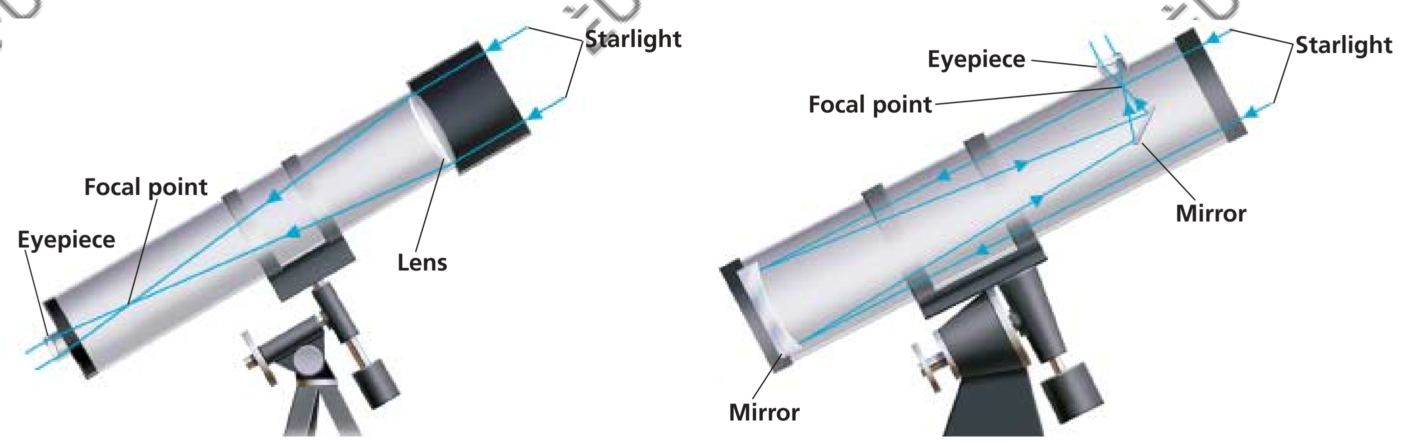
Our eyes can see detail, but some things are too small or too far away to see. Our ability to see the detail of distant objects in the sky began with the Italian scientist Galileo. In 1609, he heard of a device that used two lenses to make distant objects appear closer. He built one of the devices and turned it toward the sky. For the first time, he could see that there are craters on the moon and that the Milky Way is made of stars. An example of one of these early devices is shown in **Figure 4.**

telescope an instrument that collects electromagnetic radiation from the sky and concentrates it for better observation

A **telescope** is an instrument that collects electromagnetic radiation from the sky and concentrates it for better observation. While modern telescopes are able to collect and use invisible electromagnetic radiation, the first telescopes that were developed collected only visible light. Telescopes that collect only visible light are called *optical telescopes*. The two types of optical telescopes are refracting telescopes and reflecting telescopes.

Figure 4 ▶ One of the first reflecting telescopes, which was created by Isaac Newton, can be seen at the Royal Society in London, England.

Figure 5 ▶ Reflecting and Refracting Telescopes



Refracting telescopes use lenses to gather and focus light from distant objects.

Reflecting telescopes use mirrors to gather and focus light from distant objects.

Refracting Telescopes

Lenses are clear objects shaped to bend light in special ways. The bending of light by lenses is called *refraction*. Telescopes that use a set of lenses to gather and focus light from distant objects are called **refracting telescopes.** Refracting telescopes have an objective lens that bends light that passes through the lens and focuses the light to be magnified by an eyepiece, as shown in **Figure 5.**

One problem with refracting telescopes is that the lens focuses different colors of light at different distances. For example, if an object is in focus in red light, the object will appear out of focus in blue light. Another problem with refracting telescopes is that their potential to focus on distant objects is limited by the size of their objective lens. Objective lenses that are too large will sag under their own weight and cause images to become distorted.

refracting telescope a telescope that uses a set of lenses to gather and focus light from distant objects

reflecting telescope a telescope that uses a curved mirror to gather and focus light from distant objects

Reflecting Telescopes

In the mid-1600s, Isaac Newton solved the problem of color separation that resulted from the use of lenses. He invented the **reflecting telescope,** as shown in **Figure 5,** which used a curved mirror to gather and focus light from distant objects. When light enters a reflecting telescope, the light is reflected by a large curved mirror to a second mirror. The second mirror reflects the light to the eyepiece, where the image is magnified and focused.

Unlike objective lenses in refracting telescopes, mirrors in reflecting telescopes can be made very large without affecting the quality of the image. Thus, reflecting telescopes can be much larger and can gather more light than refracting telescopes can. The largest reflecting telescopes are a pair called the Keck Telescopes in Hawaii. Each telescope is 10 m in diameter. Astronomers are tentatively planning to build an OWL, Overwhelmingly Large Telescope, that would be 100 m in diameter.

Reading Check **What are the problems with refracting telescopes? (See the Appendix for the answers to Reading Checks.)**

SCILINKS. NSTA Developed and maintained by the National Science Teachers Association

For a variety of links related to this subject, go to www.scilinks.org

Topic: Telescopes
SciLinks code: HQ61500

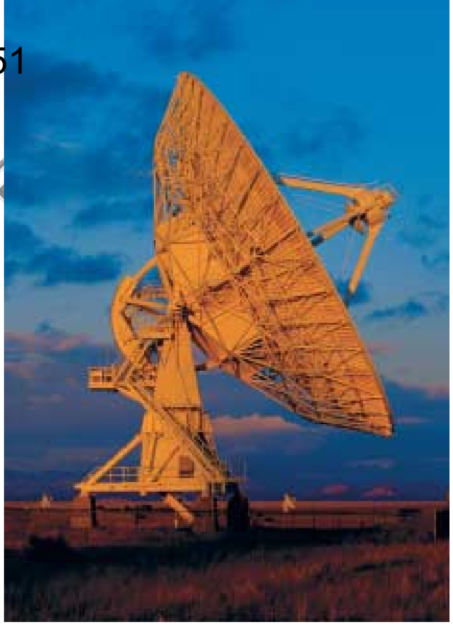


Figure 6 ▶ Radio telescopes, such as this one at the National Radio Astronomy Observatory in New Mexico, provide scientists with information about objects in space.

Telescopes for Invisible Electromagnetic Radiation

Each type of electromagnetic radiation provides scientists with information about objects in space. Scientists have developed telescopes that detect invisible radiation. For example, a radio telescope, such as the one shown in **Figure 6,** detects radio waves. There are also telescopes that detect gamma rays, X rays, and infrared rays.

One problem with using telescopes to detect invisible electromagnetic radiation is that Earth's atmosphere acts as a shield against many forms of electromagnetic radiation. Water vapor can prevents the gamma rays, X rays, and most of the infrared and ultraviolet rays from reaching Earth's surface. So, ground-based telescopes that are used to study these forms of radiation work best at high elevations, where the air is dry. But the only way to study many forms of radiation is from space.

Space-Based Astronomy

While ground-based telescopes have been critical in helping astronomers learn about the universe, valuable information has also come from spacecraft. Spacecraft that contain telescopes and other instruments have been launched to investigate planets, stars, and other distant objects. In space, Earth's atmosphere cannot interfere with the detection of electromagnetic radiation.

Reading Check **Why do scientists launch spacecraft beyond Earth's atmosphere? (See the Appendix for answers to Reading Checks.)**

Connection to ENVIRONMENTAL SCIENCE

Light Pollution

About 6,000 stars shine brightly enough to be seen with the unaided eye. Of those, about half are above the horizon at a time. But we can see those 3,000 stars only if the sky is very dark. Most people, however, live in or close to cities, where street lighting and other lighting casts a glow into the sky. This glow masks the fainter stars. In big cities, you may see only a handful of stars, instead of thousands!

The glow in the sky that obstructs our view of the stars is known as *light pollution*. Light pollution not only affects humans but also affects animals. Near the ocean, for example, street lighting can affect where and whether turtles come ashore to lay their eggs. On the beaches of Florida's developed coastline, bright lights may discourage female leatherback and green turtles from coming ashore to nest.

In recent years, efforts have been made to reduce light pollution. Reflectors on tops of streetlights would keep the light aimed at the ground instead of into the sky. Reflectors would also reduce wasted electricity. Outdoor house lights and floodlights in parking lots can be directed downward to decrease light pollution. Turning off outdoor lighting when it is not needed, such as when businesses are closed, also contributes to limiting light pollution. Taking steps such as these can improve the view of the night sky without compromising safety in our neighborhoods.

Figure 7 ▶ The *Hubble Space Telescope* is in orbit around Earth, where the telescope can detect visible and nonvisible electromagnetic radiation without the obstruction of Earth's atmosphere.

Space Telescopes

The *Hubble Space Telescope,* shown in **Figure 7,** is an example of a telescope that has been launched into space to collect electromagnetic radiation from objects in space. Another example, the *Chandra X-ray Observatory* makes remarkably clear images using X rays from objects in space, such as the remnants of exploded stars. The *Compton Gamma Ray Observatory* is no longer in space, but it detected gamma rays from objects, such as black holes. The *Spitzer Space Telescope* was launched in 2003 to detect infrared radiation. The *James Webb Space Telescope* is scheduled to be launched in 2011. When deployed in space, this telescope will detect infrared radiation from objects in space.

Figure 8 ▶ On October 15, 1997, the *Cassini-Huygens* spacecraft was launched atop a Titan IV-Centaur rocket system. The spacecraft's journey to Saturn, which the spacecraft now orbits, took 7 years and covered 2.2 billion miles.

Other Spacecraft

Since the early 1960s, spacecraft have been sent out of Earth's orbit to study other planets. Launched in 1977, the *Voyager 1* and *Voyager 2* spacecraft investigated Jupiter, Saturn, Uranus, and Neptune. These two spacecraft collected images of these planets and their moons. The *Galileo* spacecraft was in orbit around Jupiter and its moons from 1995 to 2003. This spacecraft gathered information about the composition of Jupiter's atmosphere and storm systems, which are several times larger than Earth's storm systems. The *Cassini-Huygens* spacecraft was launched in 1997, as shown in **Figure 8,** and began orbiting Saturn in 2004. In December 2004, the *Huygens* probe is scheduled to be detached from the *Cassini* orbiter to study the atmosphere of Titan, Saturn's largest moon. Like Earth, Titan has an atmosphere that is rich in nitrogen. Scientists hope to learn more about the origins of Earth by studying Titan.

Figure 9 ▶ Astronaut Jerry L. Ross conducts space assembly experiments while anchored to the foot restraint on the remote manipulator system on the space shuttle.

Human Space Exploration

Spacecraft that carry only instruments and computers are described as *robotic*. These spacecraft can explore space and travel beyond the solar system. Crewed spacecraft, or those that carry humans, have never gone beyond Earth's moon.

The first humans went into space in the 1960s. Between 1969 and 1972, NASA landed 12 people on the moon. Now, crewed spaceflights only orbit Earth. Flights, such as those aboard the space shuttles, allow people to release or repair satellites and to perform scientific experiments, as shown in **Figure 9.**

Eventually, NASA would like to send people to explore Mars. However, such a voyage would be expensive, difficult, and dangerous. The loss of two space shuttles and their crews, the *Challenger* in 1986 and the *Columbia* in 2003, have focused public attention on the risks of human space exploration.

Spinoffs of the Space Program

Space programs have brought benefits to areas outside of the field of astronomy. Satellites in orbit provide information about weather all over Earth. This information helps scientists make accurate weather predictions days in advance. Other satellites broadcast television signals from around the world or allow people to navigate cars and airplanes. Inventing ways to make objects smaller and lighter so that they can go into space has also led to improved electronics. These technological developments have been applied to radios, televisions, and other equipment. Even medical equipment has benefited from space programs. For example, heart pumps have been improved based on NASA's research on the flow of fluids through rockets.

Section 1 Review

1. **Describe** characteristics of the universe in terms of time, distance, and organization.
2. **Identify** the parts of the electromagnetic spectrum, both visible and invisible.
3. **Explain** how astronomers use electromagnetic radiation to study space.
4. **Compare** reflecting telescopes and refracting telescopes.
5. **Explain** how a radio telescope differs from an optical telescope.
6. **Identify** two examples of space telescopes and two examples of probes.

CRITICAL THINKING

7. **Identifying Relationships** Using the development of reflecting telescopes as an example, explain how scientific inquiry leads to advances in technology.
8. **Analyzing Processes** Human space exploration is expensive and dangerous. Should NASA continue human spaceflight?

CONCEPT MAPPING

9. Use the following terms to create a concept map: *electromagnetic radiation, reflecting telescope, refracting telescope, telescope, probe, astronomy, universe,* Voyager, and Cassini.

Section 2 Movements of Earth

Understanding the basic motions of Earth helps scientists understand the motions of other bodies in the solar system and the universe. These movements of Earth are also responsible for the seasons and the changes in weather.

OBJECTIVES

- **Describe** two lines of evidence for Earth's rotation.
- **Explain** how the change in apparent positions of constellations provides evidence of Earth's rotation and revolution around the sun.
- **Summarize** how Earth's rotation and revolution provide a basis for measuring time.
- **Explain** how the tilt of Earth's axis and Earth's movement cause seasons.

KEY TERMS

rotation
revolution
perihelion
aphelion
equinox
solstice

The Rotating Earth

The spinning of Earth on its axis is called **rotation.** Each complete rotation takes about one day. The most observable effects of Earth's rotation on its axis are day and night. As Earth rotates from west to east, the sun appears to rise in the east in the morning. The sun then appears to cross the sky and set in the west. At any given moment, the hemisphere of Earth that faces the sun experiences daylight. At the same time, the hemisphere of Earth that faces away from the sun experiences nighttime.

rotation the spin of a body on its axis

The Foucault Pendulum

In the 19th century, the scientist Jean-Bernard-Leon Foucault, provided evidence of Earth's rotation by using a pendulum. He created a long, heavy pendulum that rocks back and forth by attaching a wire to the ceiling and then attaching a weight to the wire. Throughout the day, the bob would swing back and forth. The path of the pendulum appeared to change over time. However, it was the floor that was moving while the pendulum's path stayed constant. Because the floor was attached to Earth, one can conclude that Earth rotates. A Foucault pendulum is shown in **Figure 1.**

Figure 1 ▶ The 12 ft arc of this Foucault pendulum in Spokane, Washington, appears to change throughout the day. However, the path of the pendulum does not actually change. Instead, Earth moves the floor as Earth rotates on its axis.

QuickLAB 10 min

Modeling a Pendulum

Procedure

1. Use a **yo-yo,** or tie a **small object** at one end of a **length of string for a pendulum.**
2. Hold the end of the string in your fingers, and swing the pendulum.
3. Twist the string in your fingers as you allow the pendulum to continue swinging.

Analysis

1. Does the direction in which the yo-yo swings change?
2. Does the yo-yo twist around with the string?
3. How does this experiment differ from the Foucault pendulum?

revolution the motion of a body that travels around another body in space; one complete trip along an orbit

perihelion the point in the orbit of a planet at which the planet is closest to the sun

aphelion the point in the orbit of a planet at which the planet is farthest from the sun

The Coriolis Effect

Evidence of the rotation of Earth can also be seen in the movement of ocean surface currents and wind belts. Ocean currents and wind belts do not move in a straight path. The rotation of Earth causes ocean currents and wind belts to be deflected to the right in the Northern Hemisphere. In the Southern Hemisphere, ocean currents and wind belts deflect to the left. This curving of the path of wind belts and ocean currents is caused by Earth's rotation and is called the *Coriolis effect*.

The Revolving Earth

As Earth spins on its axis, Earth also revolves around the sun. Even though you cannot feel Earth moving, it is traveling around the sun at an average speed of 29.8 km/s. The motion of a body that travels around another body in space is called **revolution.** Each complete revolution of Earth around the sun takes 365 1/4 days, or about one year.

Earth's Orbit

The path that a body follows as it travels around another body in space is called an *orbit*. Earth's orbit around the sun is not quite a circle. Earth's orbit is an ellipse. An *ellipse* is a closed curve whose shape is determined by two points, or foci, within the ellipse. In planetary orbits, one focus is located within the sun. No object may be located at the other focus.

Because its orbit is an ellipse, Earth is not always the same distance from the sun. The point in the orbit of a planet at which the planet is closest to the sun is the **perihelion.** The point in the orbit of a planet at which the planet is farthest from the sun is the **aphelion** (uh FEE lee uhn). As shown in **Figure 2,** Earth's aphelion distance is 152 million km. Its perihelion distance is 147 million km.

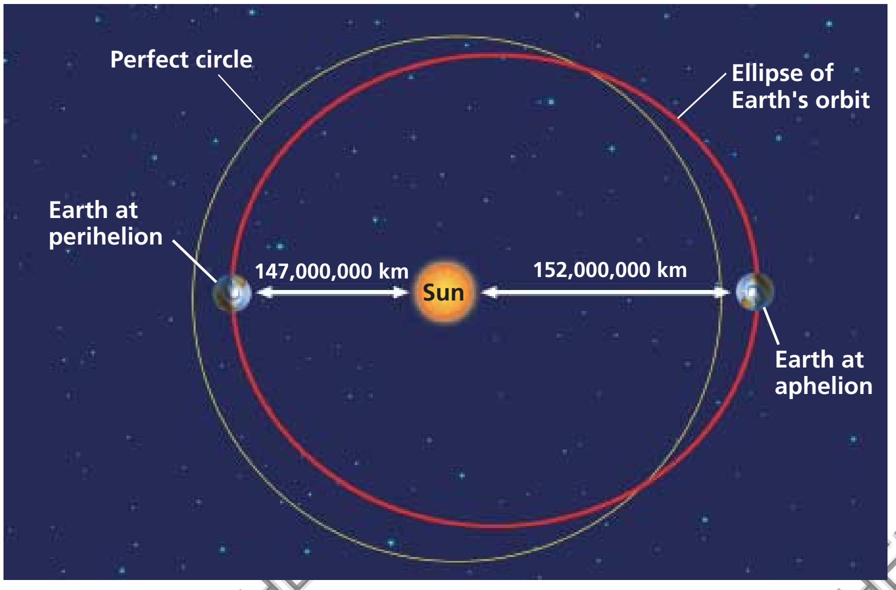


Figure 2 ▶ As Earth revolves around its elliptical orbit, the planet is farthest from the sun in July and closest to the sun in January. The elliptical orbit in this illustration has been exaggerated for emphasis.

Constellations and Earth's Motion

Evidence of Earth's revolution and rotation around the sun can be seen in the motion of constellations. A *constellation* is a group of stars that are organized in a recognizable pattern. In 1930, the International Astronomical Union divided the sky into 88 constellations. Many of the names given to these constellations came from the ancient Greeks more than 2,000 years ago. Taurus, the bull, and Orion, the hunter, are some examples of names from Greek mythology that have been given to constellations.

Evidence of Earth's Rotation

If you gaze up at a constellation in the evening sky over a period of several hours, you may notice that the constellation appears to have changed its position in the sky. However, the constellation's movement has not caused the constellation's change in position. The rotation of Earth on its axis causes the change in position. Thus, Earth is moving, and the constellation is not moving.

Evidence of Earth's Revolution

A constellation's position in the evening sky will change not only because of Earth's rotation but also because of Earth's revolution around the sun. Over a period of several weeks, at the same time of the evening, a constellation's position will appear to change, as shown in **Figure 3.** But Earth's revolution around the sun causes the constellation to have different positions in the evening sky over a period of several weeks. As Earth revolves around the sun, the night side of Earth faces a different direction of the universe. Thus, different constellations will appear in the night sky as the seasons change.

Reading Check **How does the movement of constellations provide evidence of Earth's rotation and revolution? (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ In one month's period, the position of the constellations in the sky seen from Denver, Colorado, at 10 PM change because of the revolution of Earth.

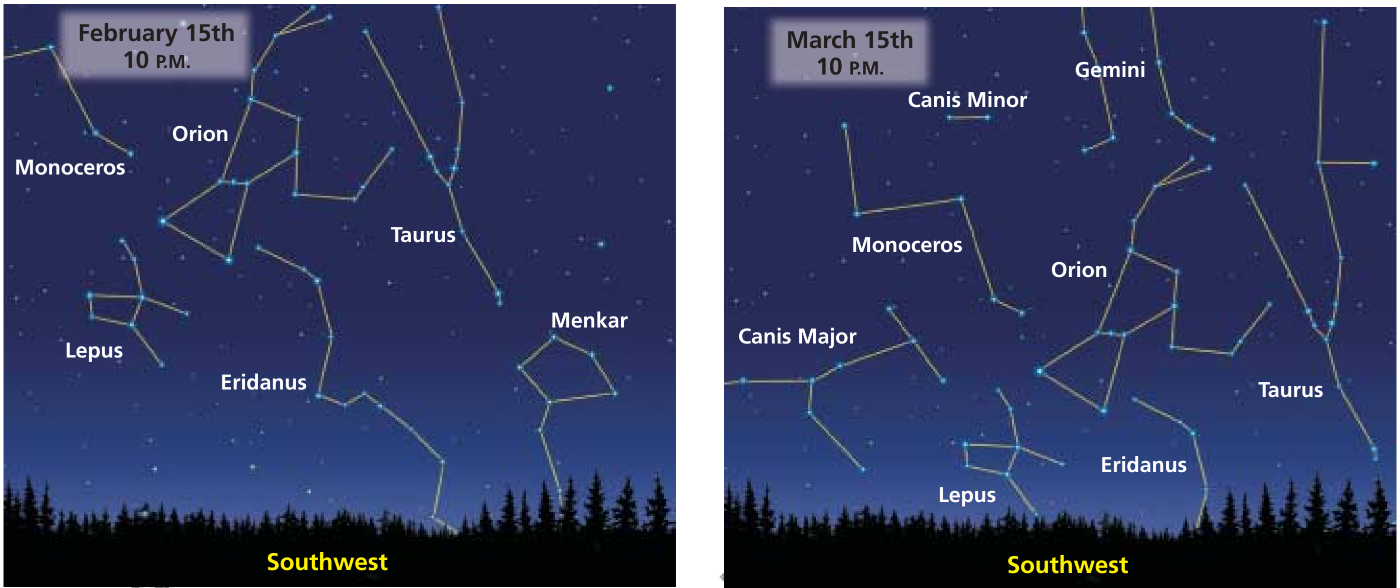


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Figure 4 ▶ This is a reconstruction of a stone calendar that the Aztecs created to help determine when to plant crops.

Measuring Time

Earth's motion provides the basis for measuring time. For example, the day and year are based on periods of Earth's motion. The day is determined by Earth's rotation on its axis. Each complete rotation of Earth on its axis takes one day, which is then broken into 24 hours.

The year is determined by Earth's revolution around the sun. Each complete revolution of Earth around the sun takes 365 1/4 days, or one year.

A month is based on the moon's motion around Earth. A month was originally determined by the period between successive full moons, which is 29.5 days. The word *month* actually comes from the word *moon*. However, the number of full moons in a year is not a whole number. Therefore, a month is now determined as roughly one-twelfth of a year.

Formation of the Calendar

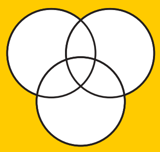
A *calendar* is a system created for measuring long intervals of time by dividing time into periods of days, weeks, months, and years. Many ancient civilizations created versions of calendars based on astronomical cycles. The ancient Egyptians were the first to use a calendar based on a solar year. The Babylonians used a 12 month lunar year. The Aztecs, who lived in what is now Mexico, also created a calendar, which is shown in **Figure 4.**

Because the year is 365 1/4 days long, the extra 1/4 day is usually ignored to make the number of days on a calendar a whole number. To keep the calendars on the same schedule as Earth's movements, we must account for the extra time. So, every four years, one day is added to the month of February. Any year that contains an extra day is called a *leap year.*

More than 2,000 years ago, Julius Caesar, of the Roman Empire, revised the calendar so that an extra day every four years was added. His successor, Augustus Caesar, made the extra day come at the end of the shortest month, February. He also made July and August long months with 31 days each.

Graphic Organizer **Venn Diagram**

Create the Graphic Organizer entitled "Venn Diagram" described in the Skills Handbook section of the Appendix. Label the circles with "Day," "Month," and "Year." Then, fill in the diagram with characteristics that each period of time shares with the other periods of time.



The Modern Calendar

Because the year is not exactly 365 1/4 days long, over centuries, the calendar gradually became misaligned with the seasons. In the late 1500s, Pope Gregory XIII formed a committee to create a calendar that would keep the calendar aligned with the seasons. We use this calendar today. In this Gregorian calendar, century years, such as 1800 and 1900, are not leap years unless the century years are exactly divisible by 400. Thus, 2000 was a leap year even though it was a century year. However, 2100, 2200, and 2300 will not be leap years.

Time Zones

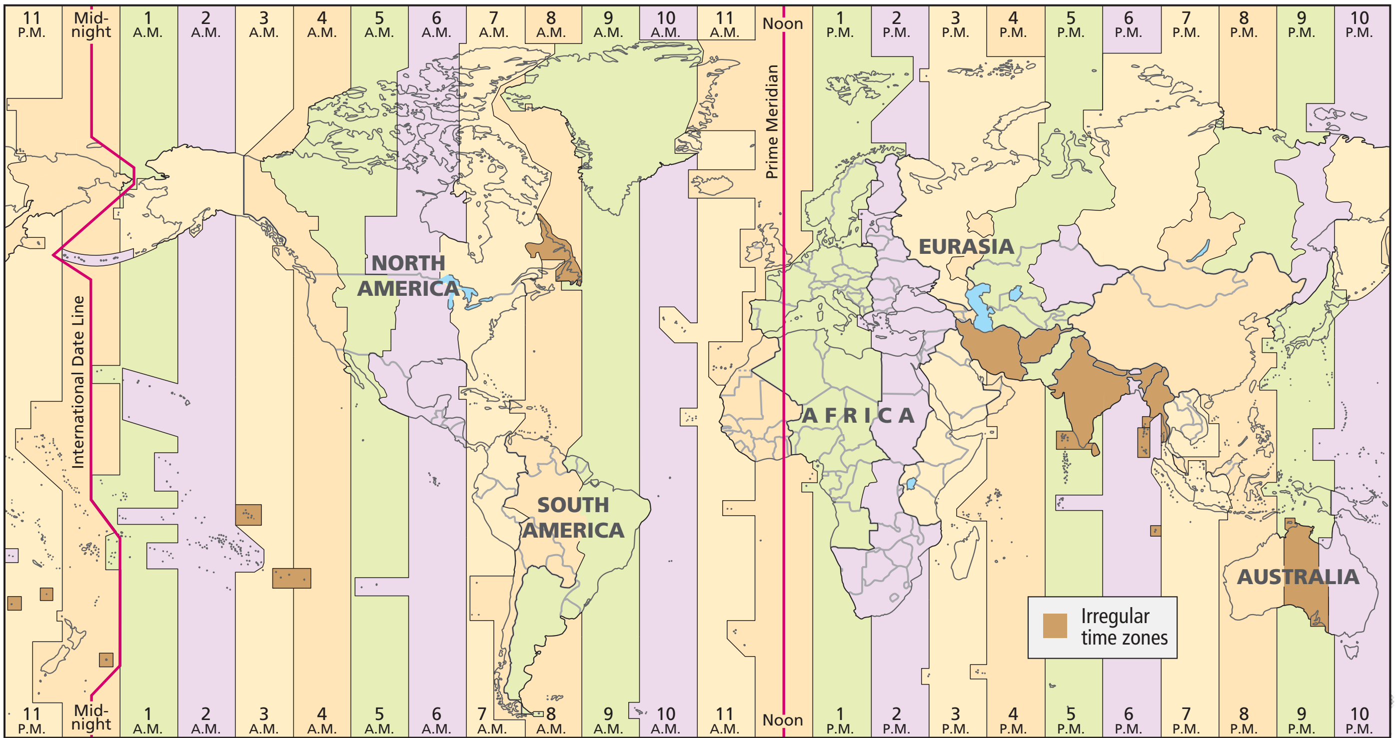
Using the sun as the basis for measuring time, we define noon as the time when the sun is highest in the sky. Because of Earth's rotation, the sun is highest above different locations on Earth at different times of day. Earth's surface has been divided into 24 standard time zones, as shown in **Figure 5,** to avoid problems created by different local times. In each zone, noon is set as the time when the sun is highest over the center of that zone. Because Earth is nearly spherical, its circumference equals 360°. If you divide 360° by the 24 hours needed for one rotation, you find that Earth rotates at a rate of 15° per hour. Therefore, each of Earth's 24 standard time zones covers about 15°. The time in each zone is one hour earlier than the time in the zone to the east of each zone.

International Date Line

There are 24 standard time zones and 24 hours in a day. But there must be some point on Earth's surface where the date changes. The *International Date Line* was established to prevent confusion. The International Date Line is a line that runs from north to south through the Pacific Ocean. When it is Friday west of the International Date Line, it is Thursday east of the line. The line is drawn so that it does not cut through islands or continents. Thus, everyone living within one country has the same date. Note where the line is drawn between Alaska and Siberia in **Figure 5.**

Reading Check **What is the purpose of the International Date Line?** **(See the Appendix for answers to Reading Checks.)**

Figure 5 ▶ Earth has been divided into 24 standard time zones. Irregular time zones may differ between 15 to 45 minutes compared to regular time zones. ***At 6 P.M. on the east coast of South America what time is it on the west coast of South America?***



Daylight Savings Time

Because of the tilt of Earth's axis, daylight time is shorter in the winter months than in the summer months. During the summer months, days are longer so that the sun rises earlier in the morning when many people are still sleeping. To take advantage of that daylight time, the United States uses *daylight savings time*. Under this system, clocks are set one hour ahead of standard time in April, which provides an additional hour of daylight during the evening. The additional hour also saves energy because the use of electricity decreases. In October, clocks are set back one hour to return to standard time. Countries in the equatorial region do not observe daylight savings time because there are not significant changes in the amount of daylight time in the equatorial region. Daylight is about 12 hours every day of the year.

The Seasons

Earth's axis is tilted at 23.5°. As Earth revolves around the sun, Earth's axis always points toward the North Star. Thus, during each revolution, the North Pole sometimes tilts toward the sun and sometimes tilts away from the sun, as shown in **Figure 6.** When the North Pole tilts toward the sun, the Northern Hemisphere has longer periods of daylight than the Southern Hemisphere does. When the North Pole tilts away from the sun, the Southern Hemisphere has longer periods of daylight.

The angle at which the sun's rays strike each part of Earth's surface changes as Earth moves through its orbit. When the North Pole tilts toward the sun, the sun's rays strike the Northern Hemisphere at a high angle. When the North Pole tilts away from the sun, the sun's rays strike the Northern Hemisphere at a low angle. When the sun's rays strike Earth at a high angle, the area receives a high concentration of solar energy.

Reading Check **What is daylight savings time? (See the Appendix for answers to Reading Checks.)**

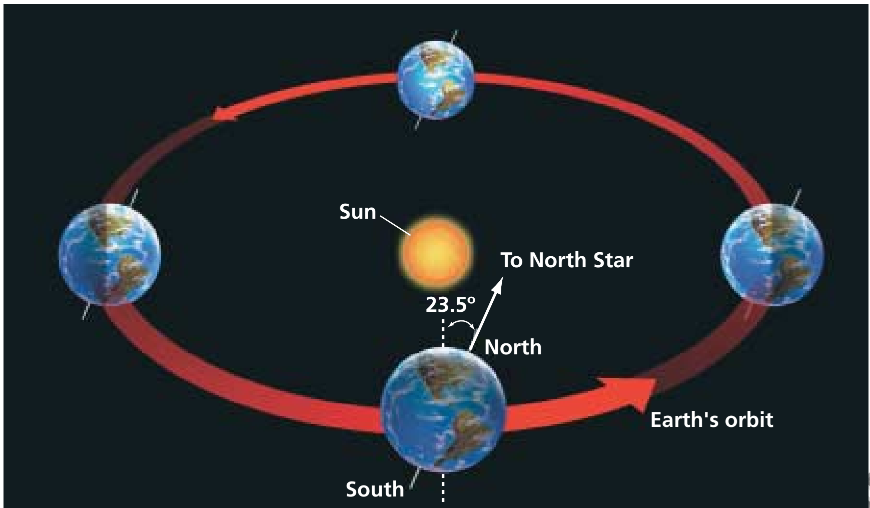


Figure 6 ▶ The direction of tilt of Earth's axis remains the same throughout Earth's orbit around the sun. Thus, the Northern Hemisphere is closer to the sun during summer months and farther from the sun during winter months.

Seasonal Weather

Changes in the angle at which the sun's rays strike Earth's surface cause the seasons. When the North Pole tilts away from the sun, the angle of the sun's rays falling on the Northern Hemisphere is low. As a result, the sun's rays spread solar energy over a large area, which leads to lower temperatures. The tilt of the North Pole away from the sun also causes the Northern Hemisphere to experience fewer daylight hours. Fewer daylight hours also mean less energy and lower temperatures. Lower temperatures cause the winter seasons. At the time, the Northern Hemisphere tilts away from the sun, the Southern Hemisphere tilts toward the sun. The sun's rays strike the Southern Hemisphere at a greater angle than they do in the Northern Hemisphere, and there are more daylight hours in the Southern Hemisphere. Therefore, the Southern Hemisphere experiences the warm summer season.

Equinoxes

The seasons fall and spring begin on days called equinoxes. An **equinox** is the moment when the sun appears to cross the celestial equator. The *celestial equator* is a line drawn on the sky directly overhead from the equator on Earth. At an equinox, the sun's rays strike Earth at a 90° angle along the equator. The hours of daylight and darkness are approximately equal everywhere on Earth on that day. The *autumnal equinox* occurs on September 22 or 23 of each year and marks the beginning of fall in the Northern Hemisphere. The *vernal equinox* occurs on March 21 or 22 of each year and marks the beginning of spring in the Northern Hemisphere.

equinox the moment when the sun appears to cross the celestial equator

QuickLAB 10 min

The Angle of the Sun's Rays

Procedure

1. Turn the lights down low or off in the classroom.
2. Place a **piece of paper** on the floor. Hold a **flashlight** 1 m above the paper, and shine the light of the flashlight straight down on the piece of paper.
3. Have a partner outline the perimeter of the circle of light cast by the flashlight on the paper. Label the circle "90° angle." Place a clean piece of paper on the floor.
4. At a height of 1/2 m from the floor, shine the light of the flashlight on the paper at an angle. Make sure the distance between the flashlight and the paper is 1 m.
5. Have a partner outline the perimeter of the circle of light cast by the flashlight on the paper. Label the circle "low angle."

Analysis

1. Compare the two circles drawn in steps 3 and 5. Which circle concentrates the light in a smaller area?
2. Which circle would most likely model the sun's rays striking Earth during the summer season?

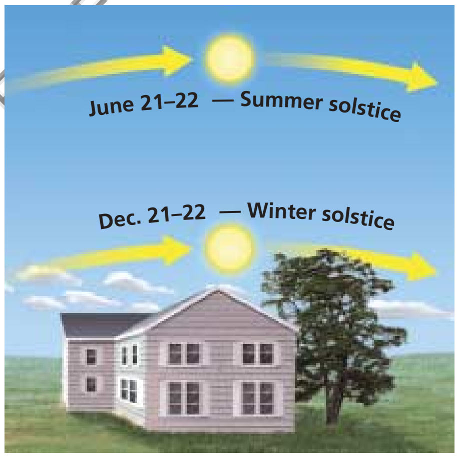


Figure 7 ▶ In the Northern Hemisphere, the sun appears to follow its highest path across the sky on the summer solstice and its lowest path across the sky on the winter solstice.

solstice the point at which the sun is as far north or as far south of the equator as possible

Summer Solstices

The seasons of summer and winter begin on days called **solstices.** Each year on June 21 or 22, the North Pole's tilt toward the sun is greatest. On this day, the sun's rays strike Earth at a 90° angle along the Tropic of Cancer, which is located at 23.5° north latitude. This day is called the *summer solstice* and marks the beginning of summer in the Northern Hemisphere. *Solstice* means "sun stop" and refers to the fact that in the Northern Hemisphere, the sun follows its highest path across the sky on that day, as shown in **Figure 7.**

The Northern Hemisphere has the most hours of daylight at the summer solstice. The farther north of the equator you are, the longer the period of daylight you have. North of the Arctic Circle, which is located at 66.5° north latitude, there are 24 hours of daylight at the summer solstice. At the other extreme, south of the Antarctic Circle, there are 24 hours of darkness at that time.

Winter Solstices

By December, the North Pole is tilted to the farthest point away from the sun. On December 21 or 22, the sun's rays strike Earth at a 90° angle along the Tropic of Capricorn, which is located at 23.5° south latitude. This day is called the *winter solstice*. It marks the beginning of winter in the Northern Hemisphere. At the winter solstice, the Northern Hemisphere has the fewest daylight hours. The sun follows its lowest path across the sky. Places that are north of the Arctic Circle then have 24 hours of darkness. However, places that are south of the Antarctic Circle have 24 hours of daylight at that time.

Section 2 Review

1. **Explain** how the apparent change of position of constellations over time provides evidence of Earth's revolution around the sun.
2. **Describe** two lines of evidence that indicate that Earth is rotating.
3. **Summarize** how movements of Earth provide a basis for measuring time.
4. **Explain** why today's calendars have leap years.
5. **Identify** two advantages in using daylight savings time.
6. **Explain** how the tilt of Earth's axis and Earth's movements cause seasons.
7. **Identify** the position of Earth in relation to the sun that causes winter in the Northern Hemisphere.
8. **Describe** the position of Earth in relation to the sun during the Northern Hemisphere's summer solstice.

CRITICAL THINKING

9. **Understanding Relationships** How can it be that Earth is at perihelion during wintertime in the Northern Hemisphere?
10. **Predicting Consequences** Explain how measurements of time might differ if Earth did not rotate on its axis.

CONCEPT MAPPING

11. Use the following terms to create a concept map: *revolution, perihelion, aphelion, rotation, ellipse, orbit, rotation, Foucault pendulum, Coriolis effect, Earth,* and *constellation.*

Chapter 26 Highlights

Sections

1 Viewing the Universe

Key Terms

astronomy, 659
galaxy, 660
astronomical unit, 660
electromagnetic spectrum, 661
telescope, 662
refracting telescope, 663
reflecting telescope, 663

Key Concepts

- The universe formed about 14 billion years ago in a giant explosion and has been expanding since that time.
- The electromagnetic spectrum contains all of the frequencies or wavelengths of electromagnetic radiation. Scientists use this radiation to study the universe.
- Refracting telescopes use lenses to gather and focus light, while reflecting telescopes use curved mirrors to gather and focus light.
- Space programs have led to improved technology in areas such as airplane navigation, weather forecasting, and medical equipment.

2 Movements of Earth

rotation, 667
revolution, 668
perihelion, 668
aphelion, 668
equinox, 673
solstice, 674

- Earth's rotation is evidenced by the change from day to night, the apparent motion of constellations, the Foucault pendulum, and the Coriolis effect.
- Earth's revolution around the sun is evidenced by the apparent motion of constellations.
- Movements of Earth provide a basis for measuring time. One revolution of Earth around the sun is equal to one year. One rotation of Earth on its axis is equal to one day.
- The angle of the sun's rays changes throughout the year and leads to seasonal change on Earth's surface.

Chapter 26 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *electromagnetic spectrum*
2. *galaxy*
3. *perihelion*

For each pair of terms, explain how the meanings of the terms differ.

4. *reflecting telescope* and *refracting telescope*
5. *solstice* and *equinox*
6. *rotation* and *revolution*

Understanding Key Concepts

7. Stars organized into a pattern are
   - **a.** perihelions.
   - **b.** satellites.
   - **c.** constellations.
   - **d.** telescopes.

8. Days are caused by Earth's
   - **a.** perihelion.
   - **b.** aphelion.
   - **c.** revolution.
   - **d.** rotation.

9. The seasons are caused by
   - **a.** Earth's distance from the sun.
   - **b.** the angle of Earth's axis.
   - **c.** the sun's temperature.
   - **d.** the calendar.

10. Which of the following is a tool that is used by astronomers to study radiation?
    - **a.** a computer model
    - **b.** a ground-based telescope
    - **c.** a Foucault pendulum
    - **d.** a calendar

11. Which of the following is evidence of Earth's revolution?
    - **a.** the Foucault pendulum
    - **b.** the Coriolis effect
    - **c.** night and day
    - **d.** constellation movement

12. Which of the following forms of radiation can be shielded by Earth's atmosphere?
    - **a.** gamma rays
    - **b.** radio waves
    - **c.** visible light
    - **d.** All of the above

13. Which of the following is not a space telescope?
    - **a.** *Hubble Space Telescope*
    - **b.** *Chandra X-ray Observatory*
    - **c.** *Challenger*
    - **d.** *Spitzer Space Telescope*

14. Which of the following marks the beginning of spring in the Northern Hemisphere?
    - **a.** vernal equinox
    - **b.** autumnol equinox
    - **c.** summer solstice
    - **d.** winter solstice

15. Which of the following is evidence of Earth's rotation?
    - **a.** the Foucault pendulum
    - **b.** day and night
    - **c.** the Coriolis effect
    - **d.** All of the above

Short Answer

16. Which two forms of electromagnetic radiation have the shortest wavelengths?
17. What is an advantage of using orbiting telescopes rather than ground-based telescopes?
18. Why does the rotation of Earth require people to establish time zones?
19. What is a leap year, and what purpose does it serve?
20. What line on Earth's surface marks where the date changes?
21. How does the tilt of Earth's axis cause the seasons?

Critical Thinking

22. Evaluating Data If telescopes had not been developed, how would our knowledge of the universe be different?

23. Analyzing Ideas In each time zone, it gets dark earlier on the eastern side of the zone than on the western side. Explain why.

24. Applying Ideas How would seasons be different if Earth was not tilted on its axis?

25. Making Inferences What limitation of a refracting telescope could be overcome by placing the telescope in space? Explain your answer.

Concept Mapping

26. Use the following terms to create a concept map: *Galileo, probe, telescope, constellation, rotation, revolution, Foucault pendulum, Coriolis effect, equinox, solstice,* and *astronomy.*

Math Skills

27. Making Calculations A certain star is 1.135×10^{14} km away from Earth. If light travels at 9.4607×10^{12} km per year, how long will it take for light from the star to reach Earth?

28. Applying Quantities At aphelion, Earth is 152,000,000 km from the sun. At perihelion, the two bodies are 147,000,000 km apart. What is the difference in kilometers between Earth's farthest point from the sun and Earth's closest point to the sun?

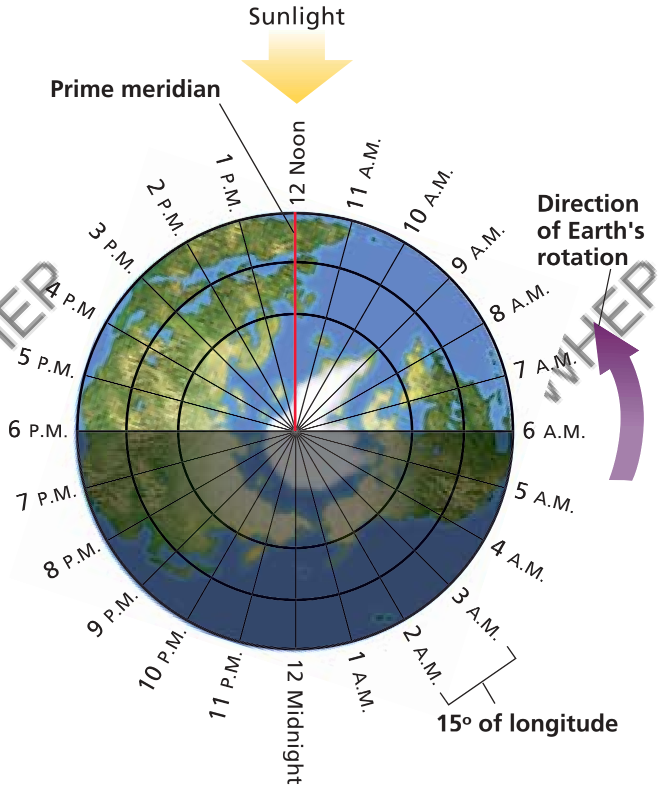
Writing Skills

29. Creative Writing Imagine that you are the head of a space program that has created the first orbiting telescope. Write a press release that explains to the public why your space agency has spent billions of dollars to build and launch a space telescope.

30. Communicating Main Ideas Explain how the Foucault pendulum and the Coriolis effect provide evidence of Earth's rotation.

Interpreting Graphics

The diagram below shows the different time zones of the world by looking down at the North Pole. Use the diagram to answer the questions that follow.



31. If it is 6 P.M. at the prime meridian, what is the time on the opposite side of the world?

32. On the diagram, it is 9 P.M. in Japan and 2 A.M. in Alaska. How many degrees apart are Alaska and Japan?

33. If it is 6 A.M. in Alaska, what time is it in Japan?

34. How many hours are in 120°?

Chapter 26 Standardized Test Prep

Understanding Concepts

Directions (1–5): **For** *each* **question, write on a sheet of paper the letter of the correct answer.**

1 Earth is closest to the sun at which of the following points in its orbit?
A. aphelion
B. perihelion
C. an equinox
D. a solstice

2 What object is located at one of the focus points for the orbit of each planet in the solar system?
F. Earth is located at one of the focus points in the orbit of each planet in the solar system.
G. A moon of each planet is located at one of the focus points in that planet's orbit.
H. The sun is one of the focus points in the orbit of each planet in the solar system.
I. The orbits of the planets do not share any common focus points.

3 Earth revolves around the sun about once every
A. 1 hour
B. 24 hours
C. 1 month
D. 365 days

4 Which of the following statements describes the position of Earth during the equinoxes?
F. The North Pole tilts 23.5° toward the sun.
G. The South Pole tilts 23.5° toward the sun.
H. Rays from the sun strike the equator at a 90° angle.
I. Earth's axis tilts 90° and points directly at the sun.

5 Which of the following statements about the electromagnetic spectrum is true?
A. It moves slower than the speed of light.
B. It consists of waves of varying lengths.
C. The shortest wavelengths are orange and red.
D. Scientists can only detect waves of visible light.

Directions (6–8): **For** *each* **question, write a short response.**

6 In what year did NASA first land astronauts on the moon?

7 What is the term that describes a spacecraft sent from Earth to another planet?

8 How does the wavelength of gamma rays compare to the wavelength of visible light?

Reading Skills

Directions (9–10): **Read the passage below. Then, answer the questions.**

The Chandler Wobble

In 1891, an American astronomer named Seth Carlo Chandler, Jr., discovered that Earth "wobbles" as it spins on its axis. This change in the spin of Earth's axis, known as the Chandler wobble, can be visualized if you imagine that Earth is penetrated by an enormous pen at the South Pole. This pen emerges at the North Pole and draws the pattern of rotation of Earth on its axis on a gigantic paper placed directly at the tip of the pen. If Earth did not have a wobble, you would expect the pen to draw a dot as Earth rotated on its axis. Because of the wobble, however, the pen draws a small circle. Over the course of 14 months, the pen will draw a spiral.

While the exact cause of the Chandler wobble is not known, scientists believe that it is related to the movement of the liquid center of Earth or to fluctuating pressure at the bottom of the ocean. This wobble affects celestial navigation. Because of the wobble, navigators' star charts must reflect new reference points for the North Pole and South Pole every 14 months.

9 Because of the Chandler wobble, celestial navigators must chart new reference points for the poles every 14 months. Changes in determining the location of the North Pole by using a compass are not required. Why?
A. Compasses point to Earth's magnetic north pole, not Earth's geographic North Pole.
B. Compasses automatically adapt and move with the wobble.
C. The wobble is related to stellar movements.
D. The wobble improves compass accuracy.

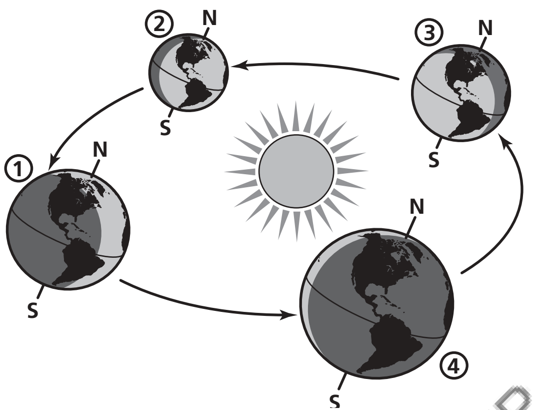
10 Which of the following statements can be inferred from the information in the passage?
F. Earth's axis moves once every 14 months.
G. The Chandler wobble prevents the liquid center of Earth from solidifying.
H. The Chandler wobble causes the oceans to move and fluctuate in pressure.
I. To locate a star, scientists must account for the wobble when using telescopes.

Interpreting Graphics

***Directions (11–14):* For *each* question below, record the correct answer on a separate sheet of paper.**

The diagram below shows the position of Earth during the four seasons. Use this diagram to answer questions 11 and 12.

Seasons and Tilt

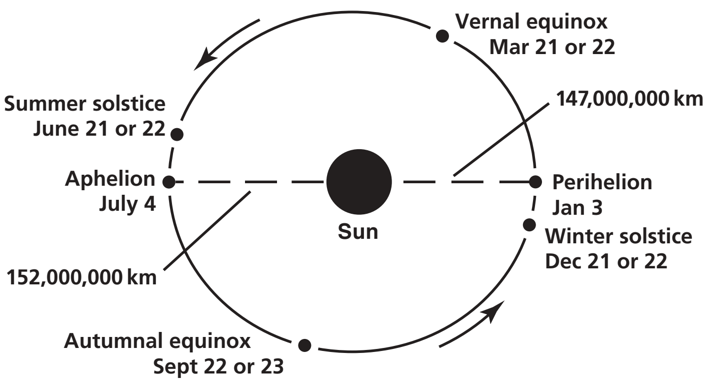


11 The Northern Hemisphere tilts toward the sun during which season?
A. winter
B. spring
C. summer
D. fall

12 The Northern Hemisphere experiences a vernal equinox when it is at which of the following positions on the diagram?
F. position 1
G. position 2
H. position 3
I. position 4

The diagram below shows the dates of specific events in Earth's orbit around the sun. Use this diagram to answer questions 13 and 14.

Orbit of Earth Around the Sun



13 Use the diagram to describe the shape of Earth's orbit around the sun, and explain how the solstices differ from the aphelion and perihelion.

14 What is the relationship between Earth and the sun on March 21 or 22? Compare this relationship with the relationship between Earth and the sun on September 22 or 23?

Test TIP

Keep an eye on your time limit. If you begin to run short on time, quickly read the remaining questions to which questions might be the easiest for you to answer.

Chapter 26

Inquiry Lab

Using Scientific Methods

Objectives

- **Design** an experiment to measure the movement of Earth.
- **Analyze** the effectiveness of your experimental design.
- **Demonstrate** how shadows can be used to measure time.

Materials

board, wooden, 20 cm × 30 cm
clock or watch
compass, magnetic
dowel, 30 cm long, 1/4 in. diameter
paper, lined
pencil
ruler, metric
tape, masking

Earth-Sun Motion

During the course of a day, the sun moves across the sky. This motion is due to Earth's rotation. In ancient times, one of the earliest devices used by people to study the sun's motion was the shadow stick. The shadow stick is a primitive form of a sundial. Before clocks were invented, sundials were one of the only means of telling time.

In this lab, you will use a shadow stick to identify how changes in a shadow are related to Earth's rotation. You will also determine how a shadow stick can be used to measure time.

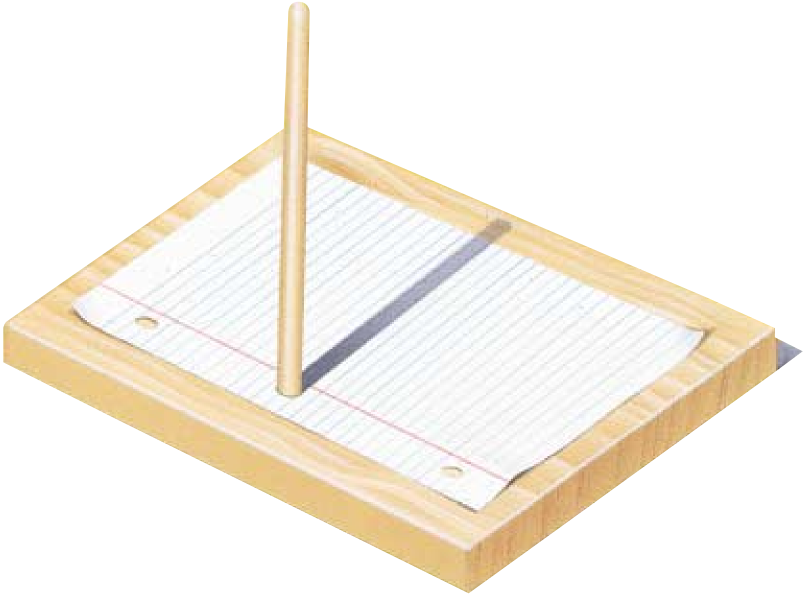
ASK A QUESTION

1. How can I measure the movement of Earth?

FORM A HYPOTHESIS

2. With a partner, build a shadow stick apparatus that is similar to the one in the illustration on the following page. Brainstorm with your partner a way in which you can use the apparatus in an experiment to measure the movement of Earth for 30 minutes. Write a few sentences that describe your design and your hypothesis about how this experiment will measure Earth's motion.

Step 2



TEST THE HYPOTHESIS

3. When you complete your experimental design, have your teacher approve your design before you begin. **CAUTION** Never look directly at the sun.
4. Follow your design to set up and to complete your experiment.
5. Take measurements every 5 min, and record this information in a data table.

ANALYZE THE RESULTS

1. **Analyzing Data** In what direction did the sun appear to move in the 30 min period?
2. **Evaluating Methods** If you made your shadow stick half as long, would its shadow move the same distance in 30 min? Explain your answer.
3. **Evaluating Methods** Would you make any changes to your experimental design? Explain your answer.

DRAW CONCLUSIONS

4. **Drawing Conclusions** In what direction does Earth rotate?
5. **Applying Conclusions** How might a shadow stick be used to tell time?

Extension

1. **Evaluating Methods** Repeat this lab at different hours of the day. Perform the lab early in the morning, early in the afternoon, and early in the evening. Record the results and any differences that you observe. Explain how shadow sticks can be used to tell direction.

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MAPS in Action

Light Sources

Map Skills Activity

This image of Earth as seen from space at night shows light sources that are almost all created by humans. The image is a composite image made from hundreds of nighttime images taken by orbiting satellites. Use the map to answer the questions below.

1. **Comparing Areas** Some climatic conditions on Earth, such as extreme cold, heat, wetness, or a thin atmosphere, make parts of our planet less habitable than other parts. Examples of areas on our planet that do not support large populations include deserts, high mountains, polar regions, and tropical rain forests. Using the image, identify regions of Earth where climatic conditions may not be able to support large human populations.

2. **Inferring Relationships** Using a map of the world and the brightness of the light sources on the image as a key, identify the locations of some of the most densely populated areas on Earth.

3. **Finding Locations** Many large cities are seaports on the coastlines of the world's oceans. By using the image, can you look along coastlines and locate light sources that might indicate the sites of large ports? Using a map of the world, name some of these cities.

4. **Inferring Relationships** By looking at the differences in the density of the light sources on the map, can you locate any borders between countries? Identify the countries on both sides of these borders.

SCIENCE AND TECHNOLOGY

Landsat Maps of Earth

▲ *Landsat 7* is the latest mission in the Landsat series of Earth-observation satellites.

Landsat satellites have been recording images of Earth for more than three decades. In that time, these Earth-scanning satellites have logged more than a million images. As Landsat satellites periodically rescan regions, the satellites create a visual history of Earth's changing landscapes.

Say Cheese!

Landsat images resemble aerial photographs. Each image records about 30,000 km^2 of Earth's surface. Landsat images are not ordinary photographs, however. Each satellite uses a scanning sensor system called a *thematic mapper,* or *TM,* to create images. The TM sensors detect visible light, which is the light recorded by an ordinary camera. The TM sensors also detect other parts of the electromagnetic spectrum that humans cannot see, such as infrared light. This capability gives Landsat images much more detail than conventional photographs have.

Once a satellite sends an image back to Earth, cartographers can use computers to create a thematic map. A thematic map is a map that illustrates a particular subject or feature. Selecting different combinations of data allows cartographers to highlight features such as river deltas, geologic faults, and mineral deposits.

Earth's Changing Surface

Landsat images appeal to Earth scientists in a variety of fields. Landsat images have enabled cartographers to map remote areas of the world. The images have allowed hydrologists to find uncharted lakes. Landsat images have also helped geologists discover oil in the Sudan, tin in Brazil, and copper in Mexico.

Recently, ecologists have begun to use Landsat images to observe changes in Earth's environment. With a series of images of the same region, taken over years, ecologists can monitor the effects of processes such as urbanization, deforestation, and soil erosion. New, useful applications of Landsat satellites may arise as the satellites continue to record Earth's changing surface.

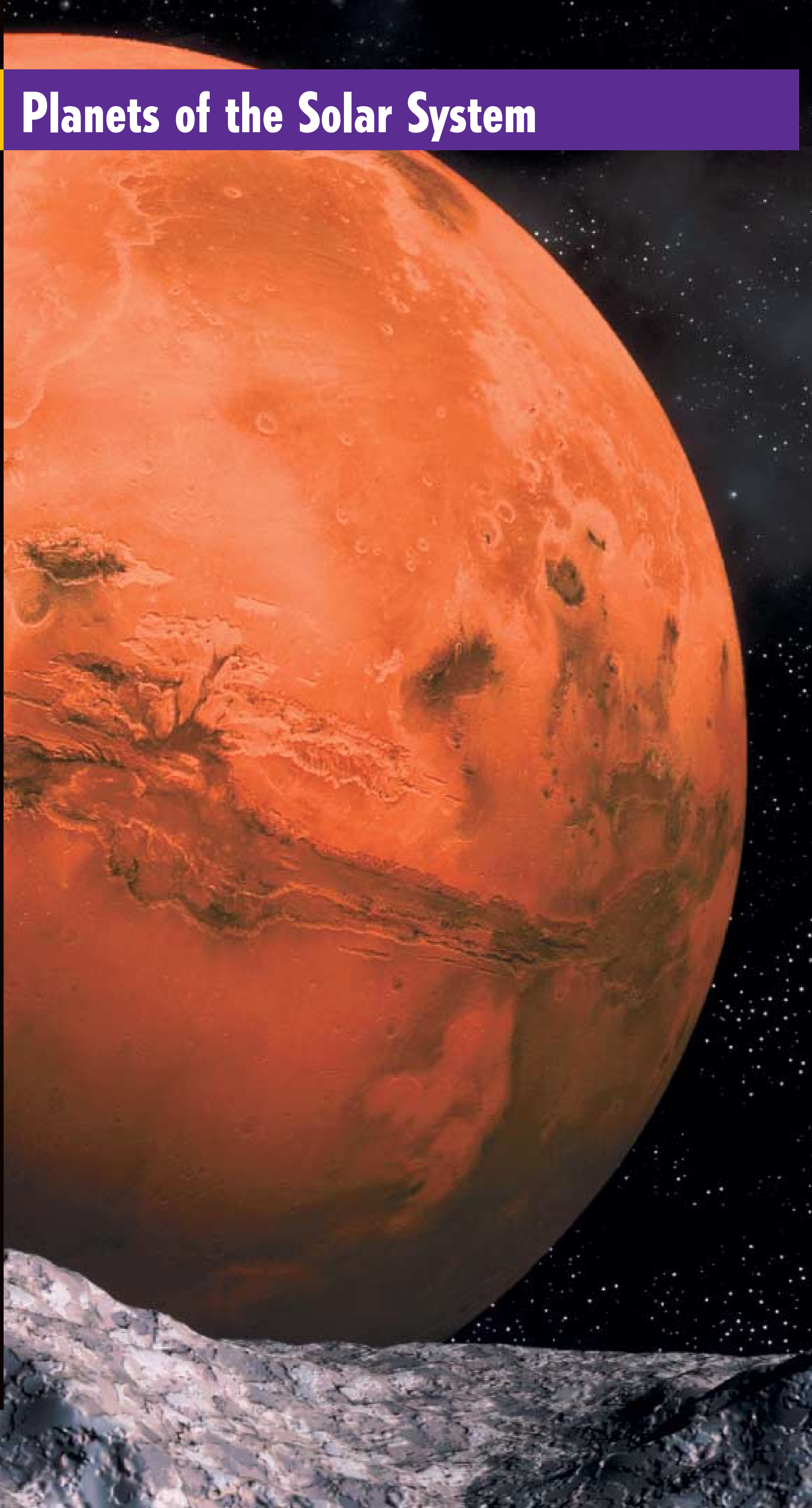
◀ The Ganges River empties into the Bay of Bengal and forms a delta. The delta is covered by a swamp forest known as the Sunderbans.

Extension

1. **Extension** How might cartographers use Landsat images to check the accuracy of maps?

Chapter 27

Planets of the Solar System



Sections

1 Formation of the Solar System

2 Models of the Solar System

3 The Inner Planets

4 The Outer Planets

What You'll Learn

- How the planets of the solar system formed
- How laws of motion govern the movements of planets
- How inner planets differ from outer planets

Why It's Relevant

Understanding the formation of the planets provides a basis for understanding Earth's processes.

PRE-READING ACTIVITY

FOLDNOTES

Three-Panel Flip Chart
Before you read this chapter, create the **FoldNote** entitled "Three-Panel Flip Chart" described in the Skills Handbook section of the Appendix. Label the flaps of the three-panel flip chart with "Inner planets," "Outer planets," and "Exoplanets." As you read the chapter, write information you learn about each category under the appropriate flap.

▶ This composite image shows how the Valles Marineris, a large canyon on the surface of Mars, may look from one of Mars's moons.

Section 1 Formation of the Solar System

The **solar system** consists of the sun and all of the planets and other bodies that revolve around the sun. **Planets** are any of the primary bodies that orbit the sun. Scientists have long debated the origins of the solar system. In the 1600s and 1700s, many scientists thought that the sun formed first and threw off the materials that later formed the planets. But in 1796, the French mathematician Pierre-Simon, marquis de Laplace, advanced a hypothesis that is now known as the *nebular hypothesis*.

The Nebular Hypothesis

Laplace's hypothesis states that the sun and the planets condensed at about the same time out of a rotating cloud of gas and dust called a *nebula*. Modern scientific calculations support Laplace's hypothesis and help explain how the sun and the planets formed from an original nebula of gas and dust.

Matter is spread throughout the universe. Some of this matter gathers into clouds of dust and gas, such as the one shown in **Figure 1.** Almost 5 billion years ago, the amount of gravity near one of these clouds increased as a result of a nearby supernova or other forces. The rotating cloud of dust and gas from which the sun and planets formed is called the **solar nebula.** Energy from collisions and pressure from gravity caused the center of the solar nebula to become hotter and denser. When the temperature at the center became high enough—about 10,000,000°C—hydrogen fusion began. A star, which is now called the sun, or *Sol,* formed. The sun is composed of about 99% of all of the matter that was contained in the solar nebula.

OBJECTIVES

- **Explain** the nebular hypothesis of the origin of the solar system.
- **Describe** how the planets formed.
- **Describe** the formation of the land, the atmosphere, and the oceans of Earth.

KEY TERMS

solar system
planet
solar nebula
planetesimal

solar system the sun and all of the planets and other bodies that travel around it

planet any of the primary bodies that orbit the sun; a similar body that orbits another star

solar nebula a rotating cloud of gas and dust from which the sun and planets formed; *also* any nebula from which stars and planets may form

Figure 1 ▶ The Orion nebula is about 1,500 light-years from Earth. Scientists study the nebula to learn about the processes that give birth to stars.

Formation of the Planets

While the sun was forming in the center of the solar nebula, planets were forming in the outer regions, as shown in **Figure 2.** Small bodies from which a planet originated in the early stages of formation of the solar system are called **planetesimals.** Some planetesimals joined together through collisions and through the force of gravity to form larger bodies called *protoplanets*. The protoplanets' gravity attracted other planetesimals in the solar nebula. These planetesimals collided with the protoplanets and added their masses to the protoplanets.

Eventually, the protoplanets became very large and condensed to form planets and moons. *Moons* are the smaller bodies that orbit the planets. Planets and moons are smaller and denser than the protoplanets.

planetesimal a small body from which a planet originated in the early stages of development of the solar system

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Topic: Origins of the Solar System
SciLinks code: HQ61087

Formation of the Inner Planets

The features of a newly formed planet depended on the distance between the protoplanet and the developing sun. The four protoplanets closest to the sun became Mercury, Venus, Earth, and Mars. They contained large percentages of heavy elements, such as iron and nickel. These planets lost their less dense gases because at the temperature of the gases, gravity was not strong enough to hold the gases. Other lighter elements may have been blown or boiled away by radiation from the sun. As the denser material sank to the centers of the planets, layers formed. The less dense material was on the outer part of the planet, and the denser material was at the center. Today, the inner planets have solid surfaces that are similar to Earth's surface. The inner planets are smaller, rockier, and denser than the outer planets.

Figure 2 ▶ **The Nebular Model of the Formation of the Solar System**

The young solar nebula begins to collapse because of gravity.

As the solar nebula rotates, it flattens and becomes warmer near its center.

Planetesimals begin to form within the swirling disk.

Formation of the Outer Planets

The next four protoplanets became Jupiter, Saturn, Uranus, and Neptune. As a group, these outer planets are very different from the small, rocky inner planets. These outer planets formed in the colder regions of the solar nebula. They were far from the sun and therefore were cold. Thus, they did not lose their lighter elements, such as helium and hydrogen, or their ices, such as water ice, methane ice, and ammonia ice.

At first, thick layers of ice surrounded small cores of heavy elements. However, because of the intense heat and pressure in the planets' interiors, the ices melted to form layers of liquids and gases. Today, these planets are referred to as *gas giants* because they are composed mostly of gases, have low density, and are huge planets. Jupiter, for example, has a density of only 24% of Earth's density but a diameter that is 11 times Earth's diameter.

The Different Planet—Pluto

Pluto is the farthest planet from the sun. Unlike the other outer planets, Pluto is very small. It is actually the smallest of the known planets and is even smaller than Earth's moon. Like the gas giants, Pluto is also very cold. Pluto may be best described as an ice ball that is made of frozen gases and rock.

Recently, astronomers have also discovered hundreds of objects that are similar to Pluto and that exist beyond Neptune's orbit. None of these objects are larger than Pluto, but Pluto is probably one of those objects. Because of this discovery, many scientists think that Pluto does not qualify as a major planet.

Reading Check **How is Pluto different from the other outer planets? (See the Appendix for answers to Reading Checks.)**

QuickLAB **5 min**

Water Planetesimals

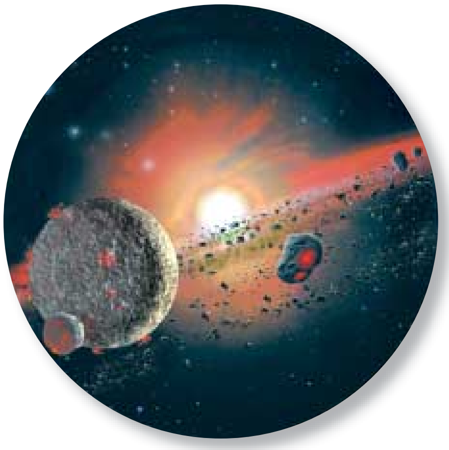
Procedure

1. Use a **medicine dropper** to place two drops of **water** about 3 cm apart on a **piece of wax paper.**
2. Lift one edge of the wax paper so that one drop of water moves toward the other drop until the drops collide.
3. Add a third drop of water to the wax paper. Then, repeat step 2.

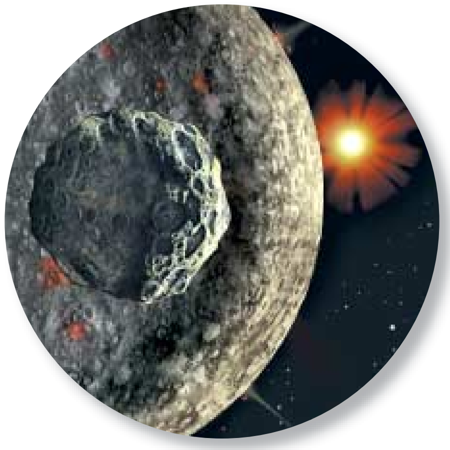
Analysis

1. What happened when the water droplets collided?
2. How does this activity model the formation of protoplanets?

As planetesimals grow, their gravitational pull increases. The largest planetesimals begin to collect more of the gas and dust of the nebula.



Small planetesimals collide with larger ones, and the planets begin to grow.



The excess dust and gas is gradually removed from the solar nebula, which leaves planets around the sun and thus creates a new solar system.

Formation of Solid Earth

When Earth first formed, it was very hot. Three sources of energy contributed to the high temperature on the new planet. First, much of the energy was produced when the planetesimals that formed the planet collided with each other. Second, the increasing weight of Earth's outer layers compressed the inner layers, which generated more energy. Third, radioactive materials that emit high-energy particles were very abundant when Earth formed. When surrounding rocks absorbed these particles, the energy of the particles' motion led to higher temperatures.

Graphic Organizer **Chain-of-Events Chart**

Create the Graphic Organizer entitled "Chain-of-Events Chart" described in the Skills Handbook section of the Appendix. Then, fill in the chart with details about each step of the formation of Earth.

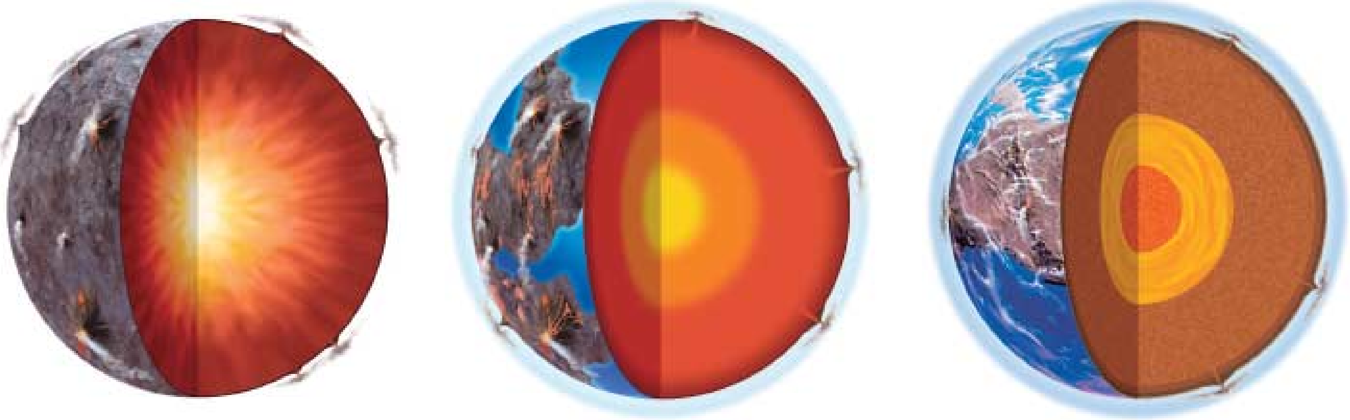
Early Solid Earth

Young Earth was hot enough to melt iron, the most common of the existing heavy elements. As Earth developed, denser materials, such as molten iron, sank to its center, and less dense materials were forced to the outer layers. This process is called *differentiation*. Differentiation caused Earth to form three distinct layers, as shown in **Figure 3.** At the center is a dense *core* that is composed mostly of iron and nickel. Around the core is the very thick layer of iron- and magnesium-rich rock called the *mantle*. The outermost layer of Earth is a thin *crust* of less dense, silica-rich rock. Today, processes that shape Earth, such as plate tectonics, are driven by heat transfer and differences in density.

Present Solid Earth

Eventually, Earth's surface cooled enough for solid rock to form. The solid rock at Earth's surface formed from less dense elements that were pushed toward the surface during differentiation. Earth's surface continued to change as a result of the heat in Earth's interior as well as through impacts and through interactions with the newly forming atmosphere.

Figure 3 ▶ **Differentiation of Earth**



During its early history, Earth cooled to form three distinct layers.

An atmosphere began to form from the water vapor and carbon dioxide released by volcanic eruptions.

Organisms produced oxygen from photosynthesis to create an oxygenated atmosphere.

Formation of Earth's Atmosphere

Like solid Earth, the atmosphere formed because of differentiation. During the original differentiation of Earth, less dense gas molecules, such as hydrogen and helium, rose to the surface. Thus, the original atmosphere of Earth consisted primarily of hydrogen and helium.

Earth's Early Atmosphere

The high concentrations of hydrogen and helium did not stay with Earth's atmosphere. Earth's gravity is too weak to hold these gases. The sun heated the gases enough so that they escaped Earth's gravity. These gases were probably blown away by the solar wind, which might have been stronger at that time than it is today. Also, Earth's magnetic field, which protects the atmosphere from the solar wind, might not have been fully developed.

Outgassing

As Earth's surface continued to form, volcanic eruptions were much more frequent than they are today. The volcanic eruptions released large amounts of gases, mainly water vapor, carbon dioxide, nitrogen, methane, sulfur dioxide, and ammonia, as shown in **Figure 4.** This process, known as *outgassing,* formed a new atmosphere.

The gases released during outgassing interacted with radiation from the sun. The solar radiation caused the ammonia and some of the water vapor in the atmosphere to break down. Most of the hydrogen that was released during this breakdown escaped into space. Some of the remaining oxygen formed *ozone,* a molecule that contains three oxygen atoms. The ozone collected in a high atmospheric layer around Earth and shielded Earth's surface from the harmful ultraviolet radiation of the sun.

Earth's Present Atmosphere

Organisms that could survive in Earth's early atmosphere developed. Some of these organisms, such as cyanobacteria and early green plants, used carbon dioxide during photosynthesis. Oxygen, a byproduct of photosynthesis, was released. So, the amount of oxygen in the atmosphere slowly increased. About 2 billion years ago, the percentage of oxygen in the atmosphere increased rapidly. Since that time, the chemical composition of the atmosphere has been similar to the present composition of the atmosphere, as shown in **Figure 5.**

Reading Check **How did green plants contribute to Earth's present-day atmosphere? (See the Appendix for answers to Reading Checks.)**

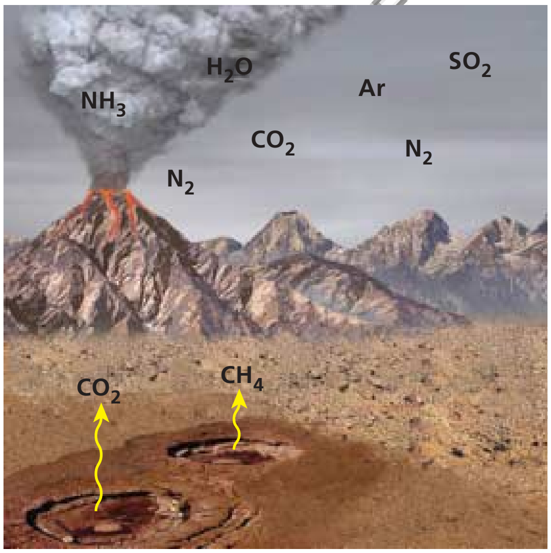


Figure 4 ▶ Earth's early atmosphere formed as volcanic eruptions released nitrogen, N_2; water vapor, H_2O; ammonia, NH_3; methane, CH_4; argon, Ar; sulfur dioxide, SO_2; and carbon dioxide, CO_2.

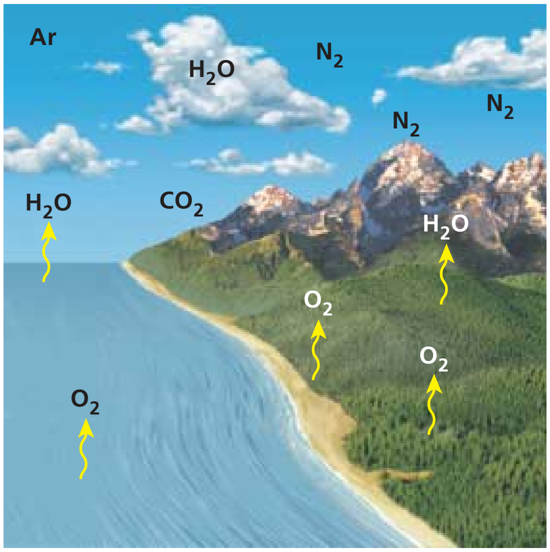


Figure 5 ▶ As Earth's surface changed, the gases in the atmosphere changed. Today, the atmosphere is 78% nitrogen, N_2; 21% oxygen, O_2; and 1% other gases.

Figure 6 ▶ Salt from the ocean can be harvested from salt flats, such as this one in Habantota, Sri Lanka.

Formation of Earth's Oceans

Some scientists think that part of Earth's water may have come from space. Icy bodies, such as comets, collided with Earth. Water from these bodies then became part of Earth's atmosphere. As Earth cooled, water vapor condensed to form rain. This liquid water collected on the surface to form the first oceans.

The first ocean was probably made of fresh water. Over millions of years, rainwater fell to Earth and ran over the land, through rivers, and into the ocean. The rainwater dissolved some of the rocks on land and carried those dissolved solids into the oceans. As more dissolved solids were carried to the oceans, the concentration of certain chemicals in the oceans increased. As the water cycled back into the atmosphere through evaporation, some of these chemicals combined to form salts. Over millions of years, water has cycled between the oceans and the atmosphere. Through this process, the oceans have become increasingly salty. Where shallow ocean water has evaporated completely, the salt precipitates and is left behind. This salt may be harvested for human use, as shown in **Figure 6.**

The Ocean's Effects on the Atmosphere

The oceans affect global temperatures in a variety of ways. One way the oceans affect temperature is by dissolving carbon dioxide from the atmosphere. Scientists think that early oceans also affected Earth's early climate by dissolving carbon dioxide. However, Earth's early atmosphere contained less carbon dioxide than the Earth's atmosphere does today. Thus, Earth's early climate was probably cooler than the global climate is today.

Section 1 Review

1. **Describe** the nebular hypothesis.
2. **Explain** how planetesimals differ from protoplanets.
3. **Describe** how planets developed.
4. **Explain** why the outer planets are more gaseous than the inner planets.
5. **List** three reasons that Earth was hot when it formed.
6. **Summarize** the process by which the land, atmosphere, and oceans of Earth formed.

CRITICAL THINKING

7. **Identifying Relationships** How does the amount of gas in an outer planet differ from the amount of gas in an inner planet? Explain your answer.
8. **Analyzing Ideas** Explain why Earth is capable of supporting life.

CONCEPT MAPPING

9. Use the following terms to make a concept map: *solar system, solar nebula, protoplanet, planetesimal, planet,* and *gas giant.*

Section 2 Models of the Solar System

The first astronomers who studied the sky thought that the stars, planets, and sun revolved around Earth. This idea led to the first model of the solar system. However, the model changed as scientists learned more about how the solar system works.

OBJECTIVES

- **Compare** the models of the universe developed by Ptolemy and Copernicus.
- **Summarize** Kepler's three laws of planetary motion.
- **Describe** how Newton explained Kepler's laws of motion.

KEY TERMS

eccentricity
orbital period
inertia

Early Models of the Solar System

More than 2,000 years ago, the Greek philosopher Aristotle suggested an Earth-centered, or *geocentric,* model of the solar system. In this model, the sun, the stars, and the planets revolved around Earth. However, this model did not explain why some planets sometimes appeared to move backward in the sky relative to the stars—a pattern called *retrograde motion*.

Around 130 CE, the Greek astronomer Claudius Ptolemy (TAHL uh mee) proposed changes to this model. Ptolemy thought that planets moved in small circles, called *epicycles,* as they revolved in larger circles around Earth. These epicycles seemed to explain why planets sometimes appeared to move backward.

In 1543 CE, a Polish astronomer named Nicolaus Copernicus proposed a sun-centered, or *heliocentric,* model of the solar system. In this model, the planets revolved around the sun in the same direction but at different speeds and distances from the sun. Fast-moving planets passed slow-moving planets. Therefore, planets that were slower than Earth appeared to move backward. **Figure 1** compares Ptolemy's and Copernicus's models. Later, the Italian scientist Galileo Galilei observed that four moons traveled around Jupiter. This observation showed him that objects can revolve around objects other than Earth.

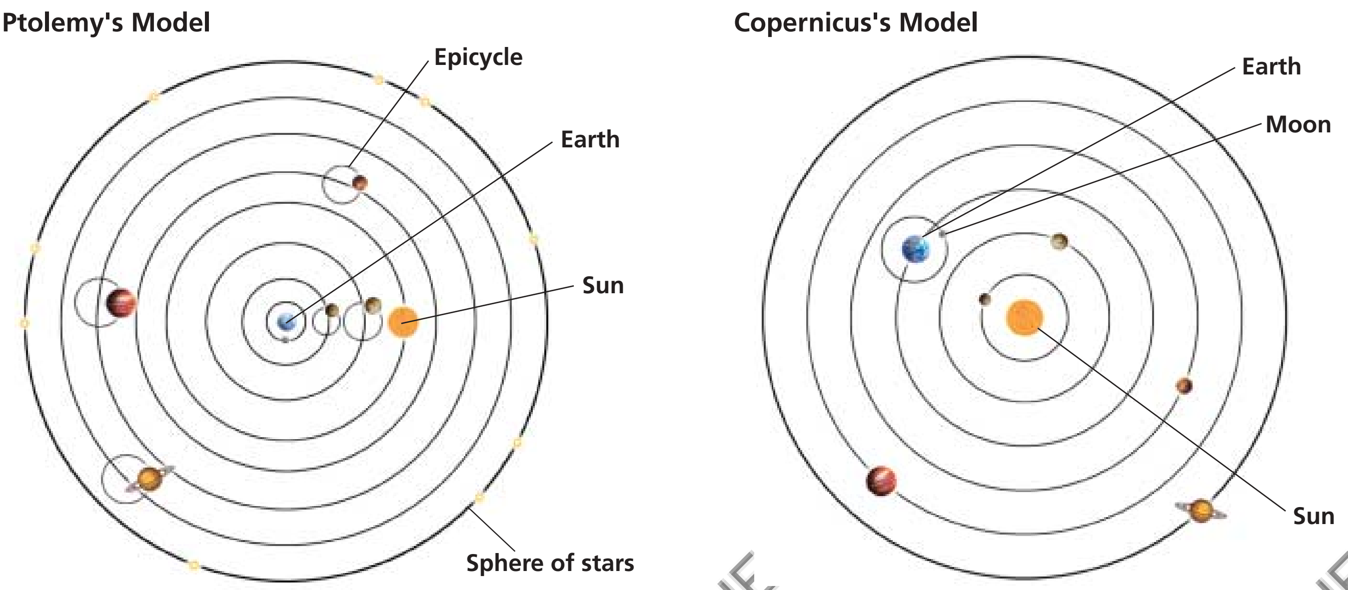


Figure 1 ▶ **Early Solar System Models** Ptolemy's solar system model (left) is Earth centered and has the planets moving in epicycles around Earth. Copernicus's solar model (right) is heliocentric and has the planets moving at different speeds around the sun.

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Kepler's Laws

Twenty years before Galileo used a telescope, a Danish astronomer named Tycho Brahe made detailed observations of the solar system. After Tycho's death, one of his assistants, Johannes Kepler, discovered patterns in Tycho's observations. These patterns led Kepler to develop three laws that explained planetary motion.

Law of Ellipses

Kepler's first law, the *law of ellipses,* states that each planet orbits the sun in a path called an ellipse, not in a circle. An *ellipse* is a closed curve whose shape is determined by two points, or *foci,* within the ellipse. In planetary orbits, one focus is located within the sun. No object is located at the other focus. The combined length of two lines, one from each focus to any one point on the ellipse, would always be the same as the length of two lines from each focus to any other one point on the same ellipse.

Elliptical orbits can vary in shape. Some orbits are elongated ellipses. Other orbit shapes are almost perfect circles. The shape of an orbit can be describe in a numerical form called eccentricity. **Eccentricity** is the degree of elongation of an elliptical orbit (symbol, e). Eccentricity is determined by dividing the distance between the foci of the ellipse by the length of the major axis. Therefore, the eccentricity of a circular orbit is $e = 0$. The eccentricity of an extreme elongated orbit, or parabolic orbit, is $e = 1$.

eccentricity the degree of elongation of an elliptical orbit (symbol, *e*)

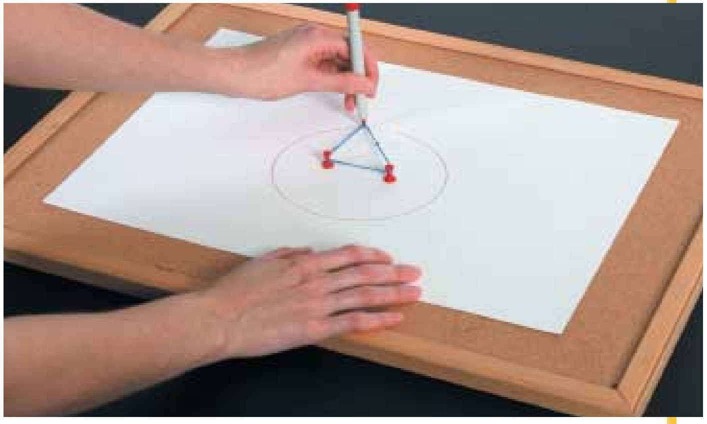
Reading Check **Define and describe an ellipse. (See the Appendix for answers to Reading Checks.)**

QuickLAB 15 min

Ellipses

Procedure

1. Cover a **cork board** with a **piece of paper.** Put **two push pins** into the cork board 5 cm apart.
2. Tie together the ends of a **string** that is 25 cm long. Loop the string around the pins.
3. Hold the string taut with a **pencil,** and move the pencil to outline an ellipse.
4. Replace the paper with another **piece of paper.** Place the pins 10 cm apart. Outline another ellipse by using the string.
5. Use another **piece of paper.** Loop the string around one pin, and outline another ellipse.



Analysis

1. Which ellipse has an eccentricity closest to 0? Which has an eccentricity closest to 1? Describe the shape of your ellipse in terms of eccentricity.
2. Describe the ellipse as you increased the distance between the foci. Describe what would happen to the ellipse if you increased the length of the string without changing the distance between the foci.

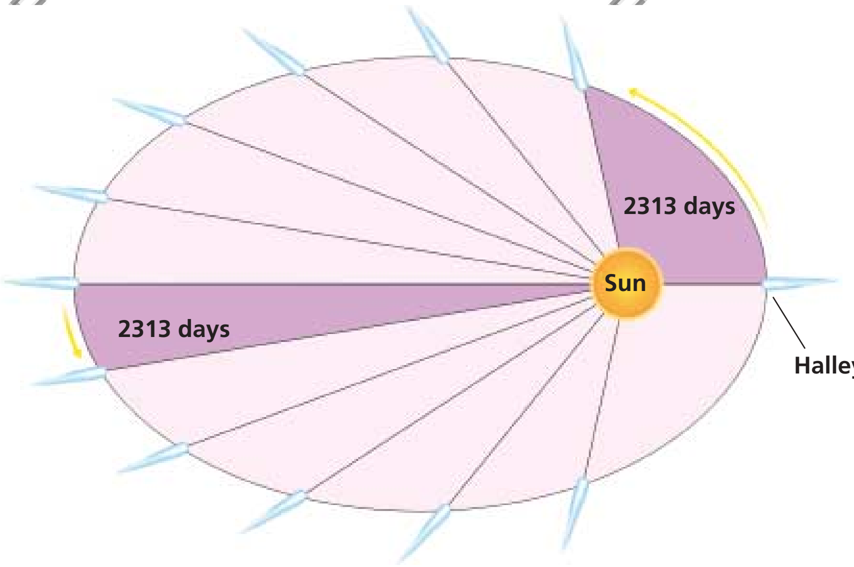


Figure 2 ▶ Kepler's second law states that the areas through which an object sweeps in a given period of time are equal.

Law of Equal Areas

Kepler's second law, the *law of equal areas,* describes the speed at which objects travel at different points in their orbits. Kepler discovered Mars moves fastest in its elliptical when it is closest to the sun. He calculated that a line from the center of the sun to the center of an object sweeps through equal areas in equal periods of time. This principle is illustrated in **Figure 2.**

Imagine a line that connects the center of the sun to the center of an object in orbit around the sun. When the object is near the sun, the imaginary line is short. The object moves relatively rapidly, and the line sweeps through a short, wide, pie-shaped sector. When the object is far from the sun, the line is long. However, the object moves relatively slowly when it is far from the sun, and the imaginary line sweeps through a long, thin, pie-shaped sector in the same period. Kepler's second law states that equal areas are covered in equal amounts of time as an object orbits the sun.

MATHPRACTICE

Law of Periods
Scientists discover an asteroid that is 0.38 AU from the sun. If 1 AU = 150 million km, how long would the planet's orbital period be in Earth years?

Law of Periods

Kepler's third law, the *law of periods,* describes the relationship between the average distance of a planet from the sun and the orbital period of the planet. The **orbital period** is the time required for a body to complete a single orbit. According to Kepler's third law, the cube of the average distance (a) of a planet from the sun is always proportional to the square of the period (p). The mathematical formula that describes this relationship is $K \times a^3 = p^2$, where K is a constant. When distance is measured in astronomical units (AU) and the period is measured in Earth years, $K = 1$ and $a^3 = p^2$.

Scientists can find out how far away the planets are from the sun by using this law, because they can measure the orbital periods by observing the planets. Jupiter's orbital period is 11.9 Earth years. The square of 11.9 is 142. The cubed number that is equal to 142 is 5.2, so Jupiter is 5.2 AU from the sun.

orbital period the time required for a body to complete a single orbit

Figure 3 ▶ In 1997, Comet Hale-Bopp was visible in the sky above the observatory on Mauna Kea in Hawaii.

Newton's Explanation of Kepler's Laws

Isaac Newton asked why the planets move in the ways that Kepler observed. The explanation that Newton gave described the motion of objects on Earth and the motion of planets in space. He hypothesized that a moving body will remain in motion and resist a change in speed or direction until an outside force acts on it. This is called **inertia.** For example, a ball rolling on a smooth surface will continue to move unless something causes it to stop or change direction.

inertia the tendency of an object to resist being moved or, if the object is moving, to resist a change in speed or direction until an outside force acts on the object

Newton's Model of Orbits

Because a planet does not follow a straight path, an outside force must cause the orbit to curve. Newton discovered that this force is *gravity,* and he realized that this attractive force exists between any two objects in the universe. The gravitational pull of the sun keeps objects, such as the comet shown in **Figure 3**, in orbit around the sun. While gravity pulls an object toward the sun, inertia keeps the object moving forward in a straight line. The sum of these two motions forms the ellipse of a stable orbit.

The farther from the sun a planet is, the weaker the sun's gravitational pull on the planet is. So, the outer planets are not pulled toward the sun as strongly as the inner ones are. As a result, the orbits of the outer planets are larger and are curved more gently, and the outer planets have longer periods of revolution than the inner planets do.

Section 2 Review

1. **Compare** Ptolemy's and Copernicus's models of the universe.
2. **Identify** the role that Galileo played in developing the heliocentric theory.
3. **Describe** the shape of planetary orbits.
4. **Explain** the law of equal areas.
5. **Summarize** Kepler's third law of planetary orbits.
6. **Describe** how Newton explained Kepler's laws by combining the effects of two forces.

CRITICAL THINKING

7. **Applying Ideas** A comet's orbit is a highly elongated ellipse. So, why does a comet spend so little time in the inner solar system?
8. **Making Comparisons** How did Kepler's explanation of the orbits of planets differ from Newton's explanation?

CONCEPT MAPPING

9. Use the following terms to create a concept map: *retrograde motion, geocentric, heliocentric, ellipse, foci, gravity,* and *inertia*.

Section 3 The Inner Planets

The planets closest to the sun are called the *inner planets*. These planets are Mercury, Venus, Earth, and Mars. The inner planets are also called **terrestrial planets,** because they are similar to Earth. These planets consist mostly of solid rock and have metallic cores. The number of moons per planet varies from zero to two. The surfaces of inner planets have bowl-shaped depressions, called *impact craters,* that were caused by collisions of the planets with other objects in space.

OBJECTIVES

- **Identify** the basic characteristics of the inner planets.
- **Compare** the characteristics of the inner planets.
- **Summarize** the features that allow Earth to sustain life.

KEY TERM

terrestrial planet

Mercury

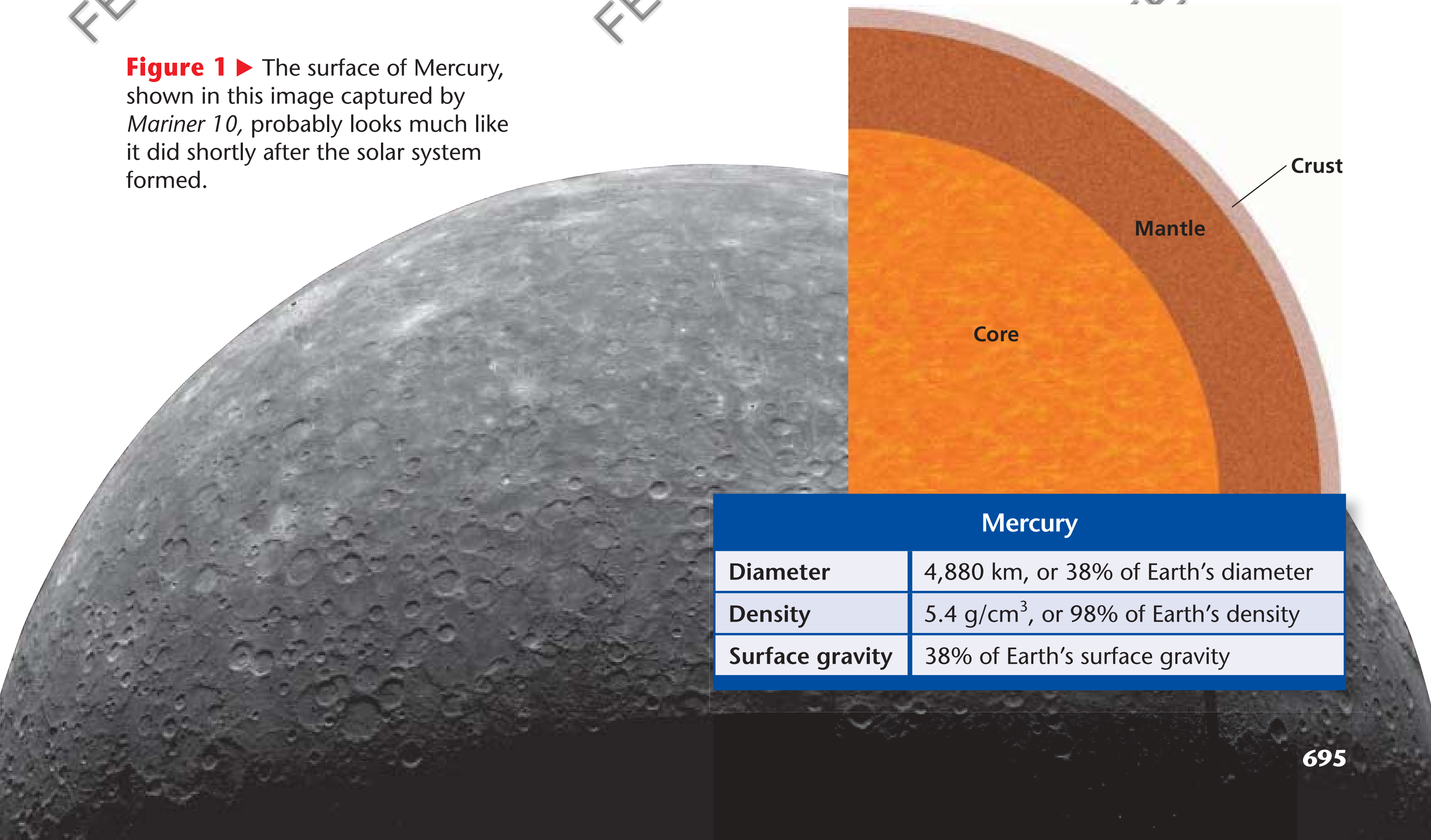
Mercury, the planet closest to the sun, circles the sun every 88 days. The ancient Romans named the planet after the messenger of the gods, who moved quickly. Mercury rotates on its axis once every 59 days.

Images of Mercury reveal a surface that is heavily cratered, as shown in **Figure 1.** The images also show a line of cliffs hundreds of kilometers long. These cliffs may be wrinkles that developed in the crust when the molten core cooled and shrank.

The absence of a dense atmosphere and the planet's slow rotation contributes to the large daily temperature range on Mercury. During the day, the temperature may reach as high as 427°C. At night, the temperature may plunge to –173°C.

terrestrial planet one of the highly dense planets nearest to the sun; Mercury, Venus, Mars, and Earth

Figure 1 ▶ The surface of Mercury, shown in this image captured by *Mariner 10,* probably looks much like it did shortly after the solar system formed.



Mercury	
Diameter	4,880 km, or 38% of Earth's diameter
Density	5.4 g/cm^3, or 98% of Earth's density
Surface gravity	38% of Earth's surface gravity

Venus

Venus is the second planet from the sun and has an orbital period of 225 days. However, Venus rotates very slowly, only once every 243 days. In some ways, Venus is Earth's twin. The two planets are of almost the same size, mass, and density. However, Venus and Earth differ greatly in other areas.

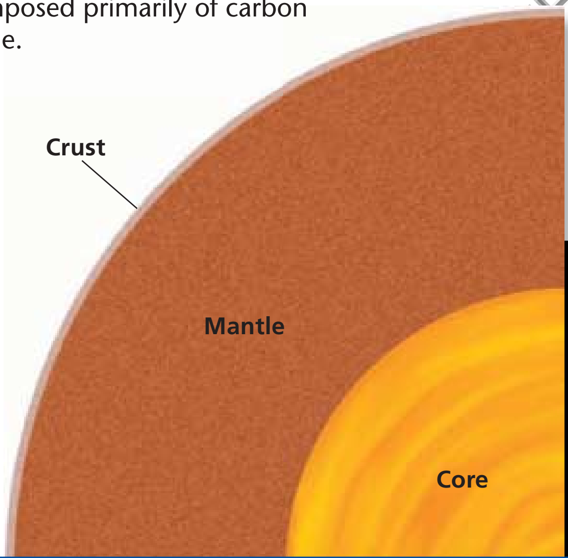
Venus's Atmosphere

The biggest difference between Earth and Venus is Venus's atmosphere. Venus's atmospheric pressure is about 90 times the pressure on Earth. The high concentration of carbon dioxide in Venus's atmosphere and Venus's relative closeness to the sun have the strongest influences on surface temperatures. Venus's atmosphere is about 96% carbon dioxide.

Solar energy that penetrates the atmosphere heats the planet's surface. The high concentration of carbon dioxide in the atmosphere blocks most of the infrared radiation from escaping. This type of heating is called a *greenhouse effect*. On Earth, the greenhouse effect warms Earth enough to allow organisms to live on the planet. But the greenhouse effect on Venus makes the average surface temperature 464°C! This phenomenon is commonly referred to as a *runaway greenhouse effect* and makes Venus's surface temperature the highest known in the solar system.

Venus also has sulfur dioxide droplets in its upper atmosphere. These droplets form a cloud layer that reflects sunlight. The cloud layer reflects the sunlight so strongly that from Earth, Venus appears to be the brightest object in the night sky, aside from Earth's moon and the sun. Because Venus appears near the sun, Venus is usually visible from Earth only in the early morning or evening. Therefore, Venus is commonly called the *evening star* or the *morning star*.

Figure 2 ▶ Venus's surface is composed of basalt and granite rocks. However, Venus's dense atmosphere is composed primarily of carbon dioxide.



Venus	
Diameter	12,100 km, or 95% of Earth's diameter
Density	5.2 g/cm^3, or 89% of Earth's density
Surface gravity	89% of Earth's surface gravity

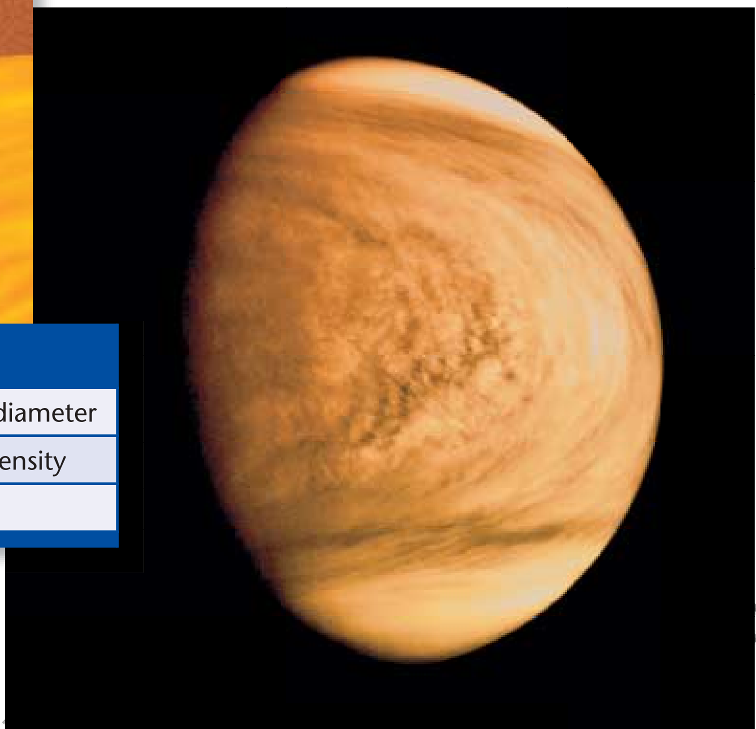


Figure 3 ▶ The scale of this computer-generated image of the Maat Mons volcano on Venus has been stretched vertically to make the topography look more dramatic. The image has also been color enhanced.

Missions to Venus

In the 1970s, the Soviet Union sent six probes to explore the surface of Venus. The probes survived in the atmosphere long enough to transmit surface images of a rocky landscape. The images showed a smooth plain and some rocks. Other instruments carried by the probes indicated that the surface of Venus is composed of basalt and granite. These two types of rock are also common on Earth.

The United States's *Magellan* satellite orbited Venus for four years in the 1990s before the satellite was steered into the planet to collect atmospheric data. *Magellan* also bounced radio waves off Venus to produce radar images of Venus's surface.

Surface Features of Venus

From the radar mapping produced by *Magellan,* scientists discovered landforms such as mountains, volcanoes, lava plains, and sand dunes. Volcanoes and lava plains are the most common features on Venus. At an elevation of 3 km, the volcano Maat Mons, which is shown in **Figure 3,** is Venus's highest volcano.

The surface of Venus is also somewhat cratered. All of the craters are of about the same age, and they are surprisingly young. This evidence and the abundance of volcanic features on Venus's surface have led some scientists to speculate that Venus undergoes a periodic resurfacing as a result of massive volcanic activity. Heat inside the planet builds up over time, which causes the volcanoes to erupt and cover the planet's surface with lava. However, scientists think that another 100 million years may pass before volcanic activity again covers Venus's surface with lava. Venus's surface is very different from Earth's surface, which is constantly changing because of the motion of tectonic plates.

Reading Check **How is Venus different from Earth? (See the Appendix for answers to Reading Checks.)**

MATHPRACTICE

Distance from the Sun Earth is about 150 million kilometers from the sun. Venus is 108.2 million kilometers from the sun. How much closer to the sun is Venus than Earth? Express your answer as a percentage.

Earth

The third planet from the sun is Earth. The orbital period of Earth is 365 1/4 days, and Earth completes one rotation on its axis every day. Earth has one large moon.

Earth has had an extremely active geologic history. Geologic records indicate that over the last 250 million years, Earth's continents separated from a single landmass and drifted to their present positions. Weathering and erosion have changed and continue to change the surface of Earth.

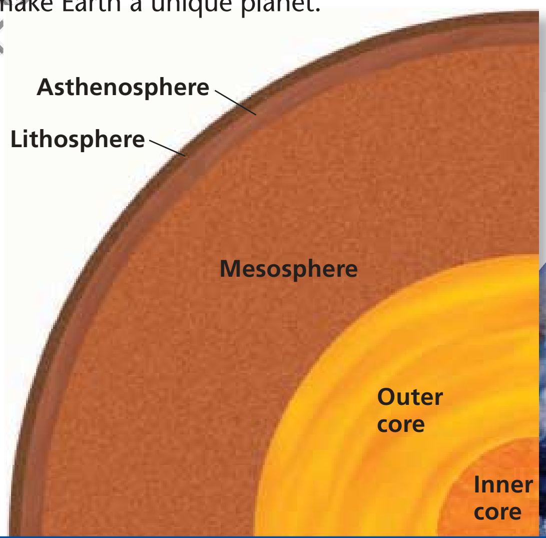
Water on Earth

Earth's unique atmosphere and distance from the sun allow water to exist in a liquid state. Mercury and Venus are so close to the sun that any liquid water on those planets would boil. Mars and the outer planets are so far from the sun that water freezes. Earth is the only planet known to have oceans of liquid water, as shown in **Figure 4.** However, scientists think that Jupiter's moon Europa may have an ocean under its icy crust.

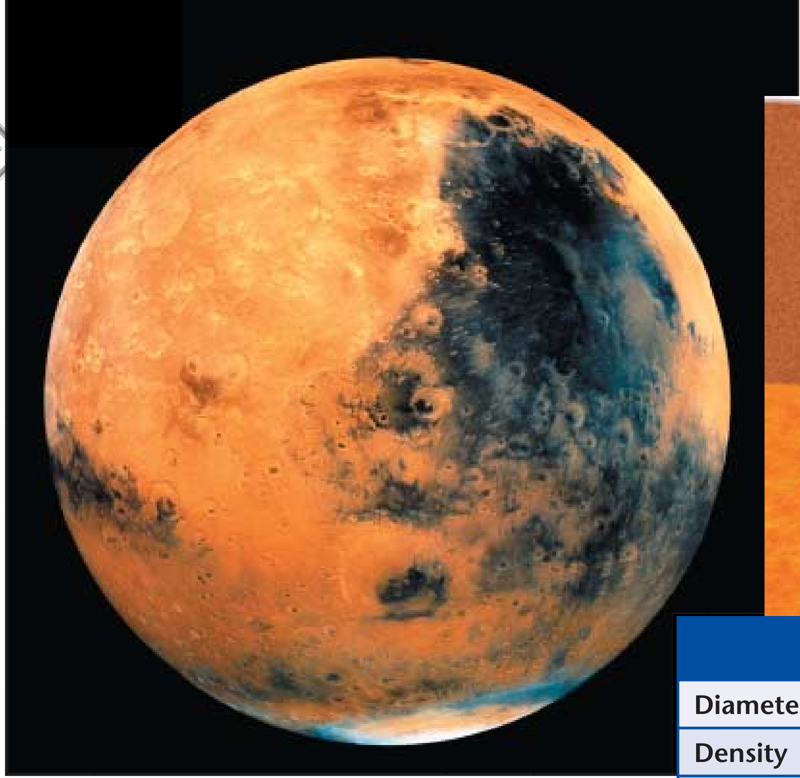
Life on Earth

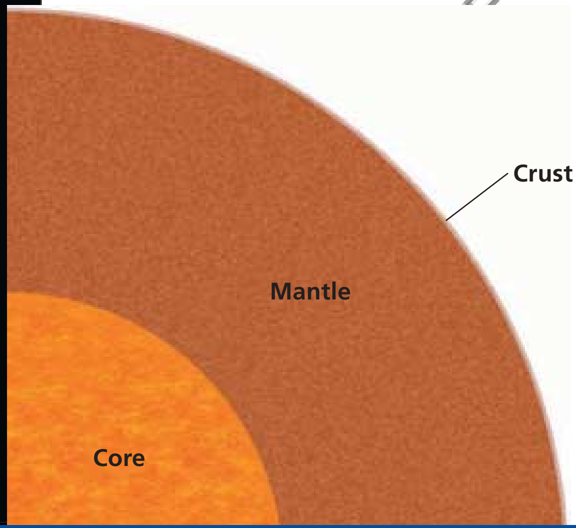
Scientists theorize that as oceans formed on Earth, liquid water dissolved carbon dioxide from the atmosphere. Because of this process, carbon dioxide did not build up in the atmosphere and solar heat was able to escape. Thus, Earth maintained the moderate temperatures needed to support life. Plants and cyanobacteria contributed free oxygen to the atmosphere. Earth is the only known planet that has the proper combination of water, temperature, and oxygen to support life.

Figure 4 ▶ Oceans of water and an atmosphere that can support life make Earth a unique planet.



Earth	
Diameter	12,756 km
Density	5.515 g/cm^3
Surface gravity	9.8 m/s^2





Mars	
Diameter	6,800 km, or 53% of Earth's diameter
Density	5.2 g/cm^3, or 71% of Earth's density
Surface gravity	38% of Earth's surface gravity

Figure 5 ▶ Mars is called the *Red Planet* because the oxidized rocks on the planet's surface give the planet a red color.

Mars

Mars, shown in **Figure 5,** is the fourth planet from the sun. At an average distance of about 228 million kilometers from the sun, Mars is about 50% farther from the sun than Earth is. Its orbital period is 687 days, and it rotates on its axis every 24 h and 37 min. Because its axis tilts at nearly the same angle that Earth's does, Mars's seasons are much like Earth's seasons.

Mars has been geologically active in its past, which is shown in part by the presence of massive volcanoes. A system of deep canyons also covers part of the surface. Valles Marineris is a canyon that is as long as the United States is wide—4,500 km. The canyon is thought to be a crack that formed in the crust as the planet cooled.

Martian Volcanoes

Tharsis Montes is one of several volcanic regions on Mars. Volcanoes in this region are 100 times as large as Earth's largest volcano. The largest volcano on Mars is Olympus Mons, which is nearly 24 km tall. It is three times as tall as Mount Everest. At 600 km across, the base of Olympus Mons is about the size of Nebraska. Scientists think that the volcano has grown so large because Mars has no moving tectonic plates. So, Olympus Mons may have had a magma source for millions of years.

Whether Martian volcanoes are still active is a question scientists have yet to answer. A *Viking* landing craft detected two geological events that produced seismic waves. These events, called *marsquakes,* may indicate that volcanoes on Mars are active.

Reading Check **Why are Martian volcanoes larger than Earth's volcanoes? (See the Appendix for answers to Reading Checks.)**

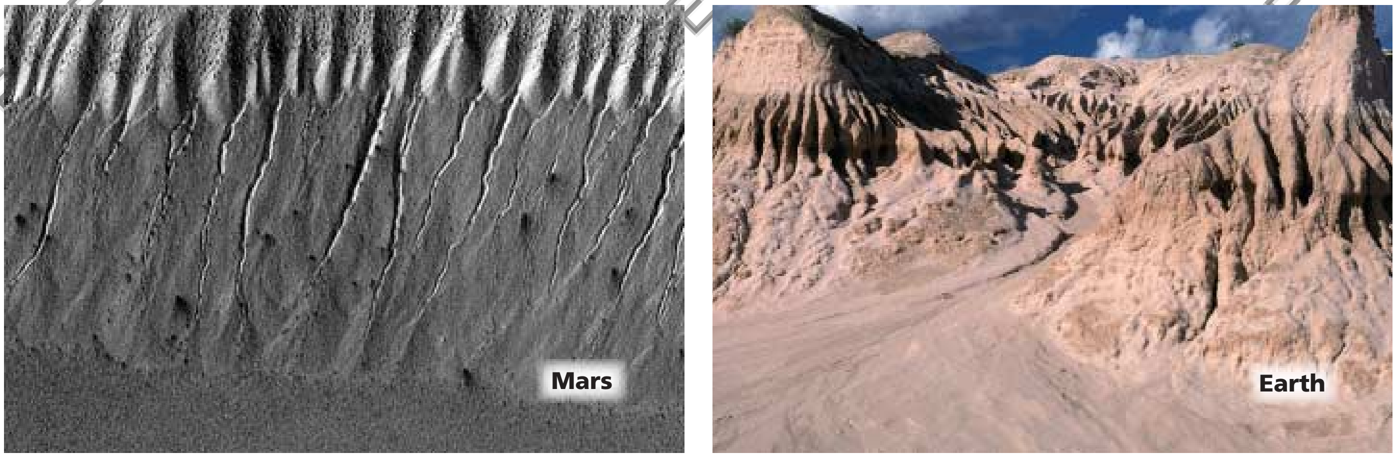


Figure 6 ▶ The images above compare the formation of gullies by possible liquid water runoff on Mars (left) with the formation of similar gullies at Mungo National Park in Australia on Earth (right). The Mungo National Park was the site of a large lake that dried up more than 10,000 years ago.

Water on Mars

The pressure and temperature of Mars's atmosphere are too low for water to exist as a liquid on Mars's surface. However, several NASA spacecraft—such as the Mars rovers, *Spirit* and *Opportunity,* which landed on Mars in 2004—have found evidence that liquid water did exist on Mars's surface in the past. Mars has many surface features that are characteristic of erosion by water, such as branching paths that look like gullies, as shown in **Figure 6.** Scientists think that other features on Mars might be evidence of vast flood plains produced by a volume of water equal to that of all five of Earth's Great Lakes.

The surface temperature on Mars ranges from 20°C near the equator during the summer to as low as –130°C near the poles during the winter. Although most of the water on Mars is trapped in polar icecaps, data from the *Mars Global Surveyor* suggest that water may also exist as permanent frost or as a liquid just below the surface. If liquid water does exist below Mars's surface, the odds of life existing on Mars will dramatically increase. However, no solid evidence of life on Mars has been found.

Section 3 Review

1. **Explain** why Mercury has such drastically different temperatures during its day and during its night.
2. **Describe** the main ways in which Venus is similar to and different from Earth.
3. **Identify** the aspects that make Earth hospitable for life.
4. **Explain** why Mars's volcanoes became so tall.
5. **Explain** why Mars does not have liquid water on its surface.
6. **Compare** the characteristics of the inner planets.

CRITICAL THINKING

7. **Making Comparisons** Describe the difference between the greenhouse effect on Venus and the greenhouse effect on Earth.
8. **Understanding Relationships** As rock cools, it contracts. How could this fact explain the presence of Valles Marineris on Mars?

CONCEPT MAPPING

9. Use the following terms to create a concept map: *Mercury, Venus, Earth, Mars, terrestrial planet, Olympus Mons, liquid water*, and *Maat Mons*.

Section 4 The Outer Planets

The five planets farthest from the sun are called the *outer planets*. They are separated from the inner planets by a ring of debris called the *asteroid belt*. Jupiter, Saturn, Uranus, and Neptune, which are shown in **Figure 1**, are called **gas giants** because they are large planets that have deep, massive atmospheres made mostly of gas. The smallest and usually the most distant planet in the solar system is Pluto. Because Pluto is different from the gas giants, it may not have formed in the same way that the other outer planets formed.

OBJECTIVES

- **Identify** the basic characteristics that make the outer planets different from terrestrial planets.
- **Compare** the characteristics of the outer planets.
- **Explain** why Pluto is different from the other eight planets.

KEY TERMS

gas giant
Kuiper belt

Gas Giants

Although the gas giants are much larger and more massive than the terrestrial planets, the gas giants are much less dense than the terrestrial planets. Unlike the terrestrial planets, the gas giants did not lose their original gases during their formation. Their large masses give them a huge amount of gravity, which helps them retain the gases. Each of the gas giants has a thick atmosphere that is made mostly of hydrogen and helium gases. A cloud layer prevents scientists from directly observing more than the topmost part of the atmosphere of the gas giants. But each planet probably has a core made of rock and metals.

Although Saturn's rings may be the most impressive, all four gas giants have ring systems that are made of dust and icy debris that orbit the planets. Most of the debris probably came from comets or other bodies.

gas giant a planet that has a deep massive atmosphere, such as Jupiter, Saturn, Uranus, or Neptune

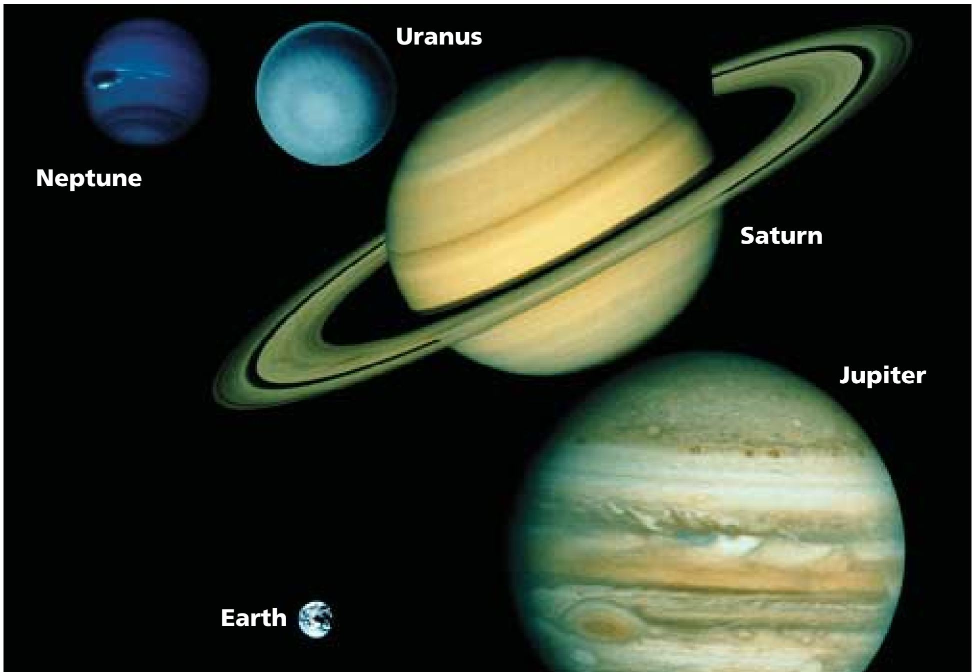


Figure 1 ▶ The four gas giants are much larger than Earth, which is the terrestrial planet shown here at the lower left.

Jupiter

Jupiter, shown in **Figure 2,** is the fifth planet from the sun and is by far the largest planet in the solar system. Its mass is more than 300 times that of Earth and is twice that of the other eight planets combined. Jupiter's orbital period is almost 12 years. Jupiter rotates on its axis faster than any other planet rotates—once every 9 h and 50 min. Jupiter has at least 60 moons, 4 of which are the size of small planets. It also has several thin rings that are made up of millions of particles.

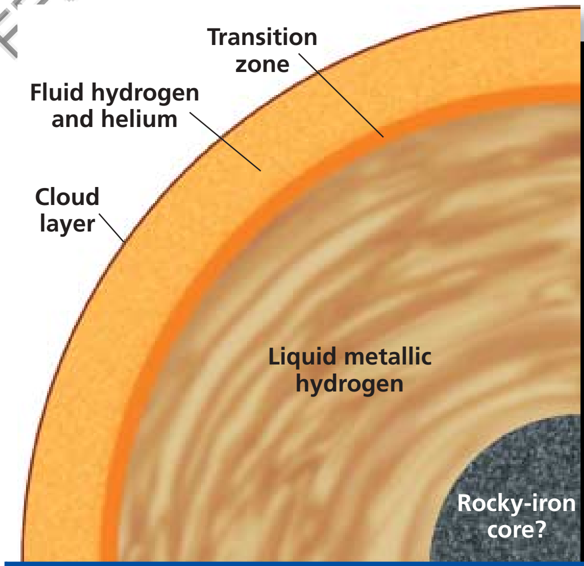
Jupiter's Atmosphere

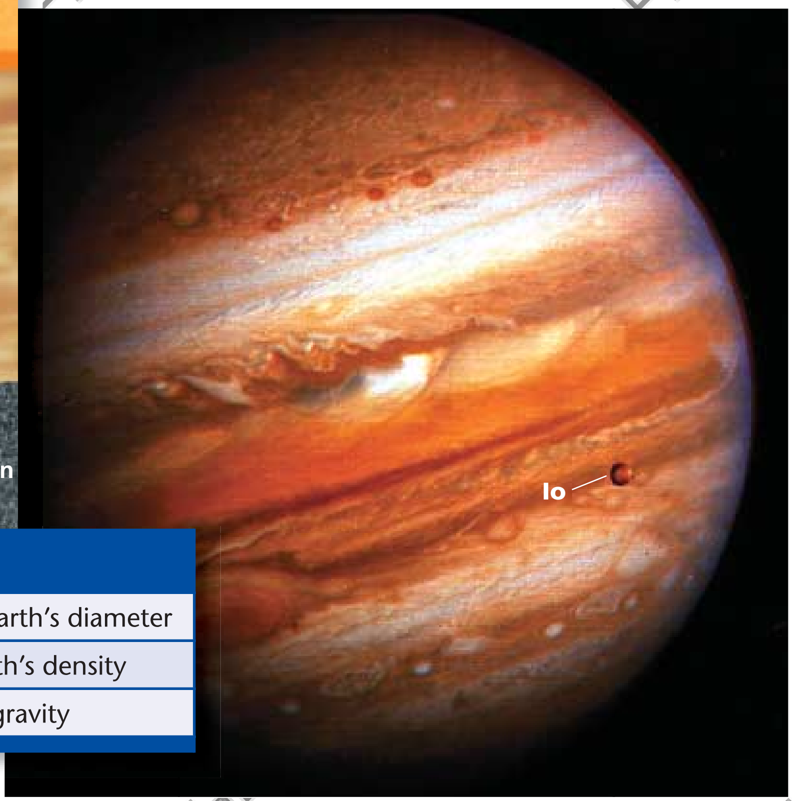
Hydrogen and helium make up 92% of Jupiter, so Jupiter's composition is much like the sun's. However, when Jupiter formed about 4.6 billion years ago, it did not have enough mass to allow nuclear fusion to begin. So, Jupiter never became a star.

The alternating light and dark bands on its surface make Jupiter unique in our solar system. Orange, gray, blue, and white bands spread out parallel to the equator. The colors suggest the presence of organic molecules mixed with ammonia, methane, and water vapor. Jupiter's rapid rotation causes these gases to swirl around the planet and form the bands. The average temperature of Jupiter's outer atmospheric layers is –160°C. Jupiter also has lightning storms and thunderstorms that are much larger than those on Earth.

Reading Check **Why didn't Jupiter become a star? (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ Jupiter is easily identified by its large size and alternating light and dark bands. One of Jupiter's larger moons can be seen in front of the planet.





Jupiter	
Diameter	143,000 km, or 11 times Earth's diameter
Density	1.33 g/cm^3, or 24% of Earth's density
Surface gravity	2.54 times Earth's surface gravity

Weather and Storms on Jupiter

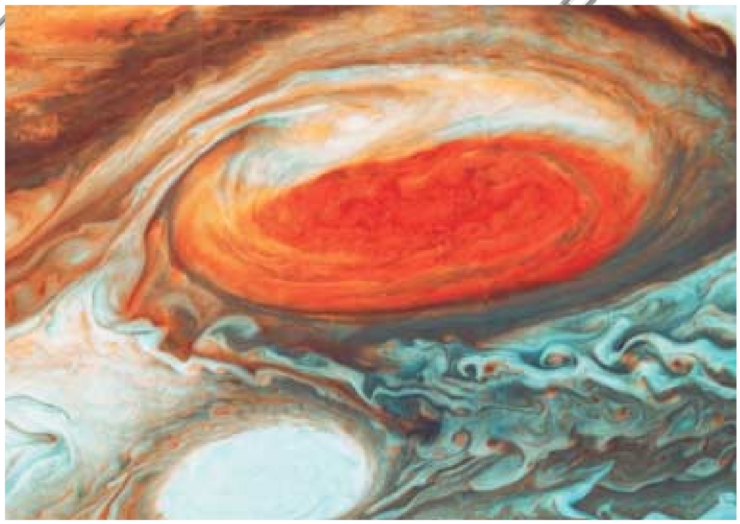


Figure 3 ▶ Jupiter's Great Red Spot is an ongoing, massive, hurricane-like storm that is about twice the diameter of Earth.

Jupiter's most distinctive feature is its *Great Red Spot,* shown in **Figure 3.** The Great Red Spot is a giant rotating storm, similar to a hurricane on Earth, that has been raging for at least several hundred years. Several other oval spots, or storms, can be seen on Jupiter, although they are usually white. Sometimes, the smaller storms are swallowed up by the larger ones. While storms are common on Jupiter's surface, only a few of the largest storms persist for a long time.

A probe dropped by the *Galileo* spacecraft measured wind speeds on Jupiter of up to 540 km/h. Because winds are caused by temperature differences, scientists have concluded that Jupiter's internal heat affects the planet's weather more than heat from the sun does. From Earth, even by using a small telescope, you can see bands of clouds on Jupiter. These bands, which vary depending on latitude, show regions of different wind speeds.

Jupiter's Interior

Jupiter's large mass causes the temperature and pressure in Jupiter's interior to be much greater than they are inside Earth. The intense pressure and temperatures as high as 30,000°C have changed Jupiter's interior into a sea of liquid, metallic hydrogen. Electric currents in this hot liquid may be the source of Jupiter's enormous magnetic field. Scientists think that Jupiter has a solid, rocky, iron core at its center.

Connection to TECHNOLOGY

Galileo Probes Jupiter

In 1995, the spacecraft *Galileo* arrived at Jupiter and began monitoring an atmospheric probe that Galileo had launched five months earlier. The 336 kg probe transmitted data about the composition and meteorology of Jupiter's atmosphere.

The data surprised mission scientists in many ways. The wind speeds that were measured were much higher than the expected wind speeds. But the most surprising discovery was that although the levels of carbon and nitrogen that were measured were consistent with what was anticipated, only one-fifth of the expected amount of water was found.

The *Galileo* spacecraft studied Jupiter and its moons through 2003. It was then crashed into Jupiter to avoid a collision with one of Jupiter's moons, Europa. No spacecraft is now in orbit around Jupiter. NASA is considering launching a mission to study Europa. *Galileo* discovered evidence of a possible subsurface ocean on Europa. So, scientists are excited about the possibility of life on this moon of Jupiter.

Graphic Organizer — Comparison Table

Create the **Graphic Organizer** entitled "Comparison Table" described in the Skills Handbook section of the Appendix. Label the columns with "Jupiter," "Saturn," Uranus," and "Neptune." Label the rows with "Diameter," "Density," "Orbital period," and "Composition." Then, fill in the table with details about the gas giants.

Saturn

Saturn, shown in **Figure 4,** is the sixth planet from the sun and has an orbital period of 29.5 years. Because it is so far from the sun, Saturn is very cold and has an average cloud-top temperature of –176°C. Saturn has at least 30 moons, and additional small moons continue to be discovered. Its largest moon, Titan, which has a diameter of 5,150 km, is half the size of Earth.

Saturn, like Jupiter, is made almost entirely of hydrogen and helium and has a rocky, iron core at its center. However, Saturn is much less dense than Jupiter. In fact, Saturn is the least dense planet in the solar system.

Saturn's Bands and Rings

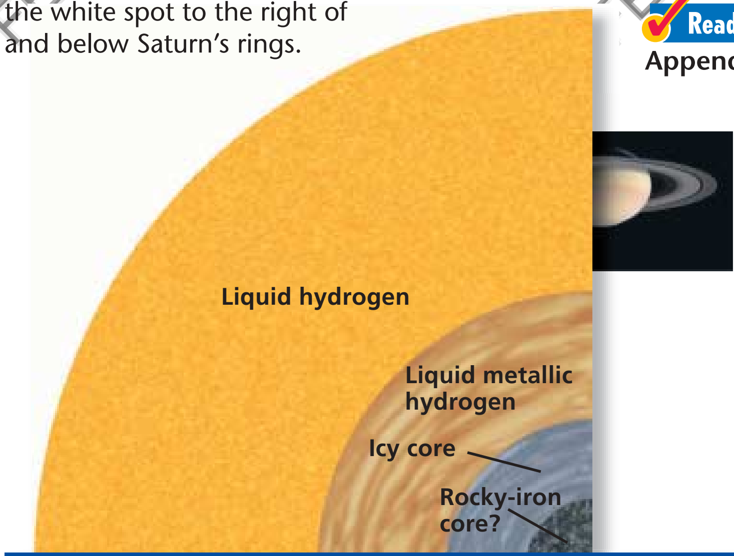
Saturn is known for its rings, which are 2 times the planet's diameter. While the other gas giants also have rings, Saturn has the most complex and extensive system of rings. The rings are made of billions of dust and ice particles. Most of the ring debris probably came from comets or other bodies.

Like Jupiter, Saturn also has bands of colored clouds that run parallel to its equator. These bands are caused by Saturn's rapid rotation. Saturn rotates on its axis every 10 h and 30 min. This rapid rotation, paired with Saturn's low density, causes Saturn to bulge at its equator and to flatten at its poles.

Scientists hope to learn more about Saturn and its moon Titan from NASA's *Cassini* spacecraft, which reached Saturn on July 1, 2004. This spacecraft will remain in orbit around Saturn for many years.

Reading Check How is Saturn similar to Jupiter? (See the Appendix for answers to Reading Checks.)

Figure 4 ▶ This composite image of Saturn taken from the *Cassini* spacecraft shows the planet's rings and an icy moon, Enceladus, which is the white spot to the right of and below Saturn's rings.



Saturn	
Diameter	120,535 km, or 9.4 times Earth's diameter
Density	0.70 g/cm^3, or 13% of Earth's density
Surface gravity	1.07 times Earth's surface gravity

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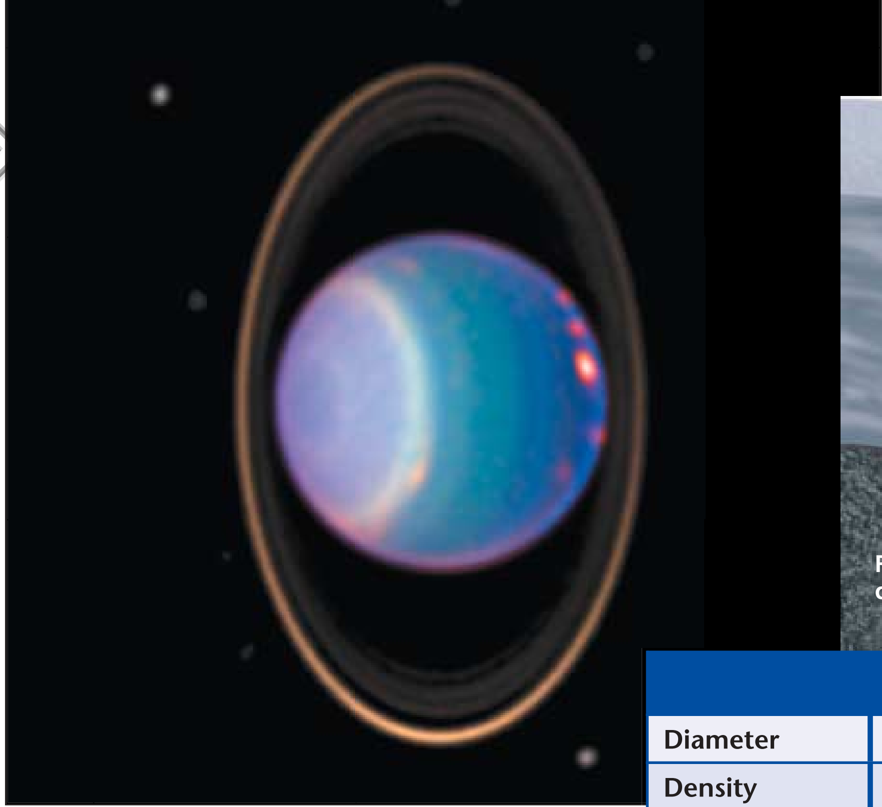
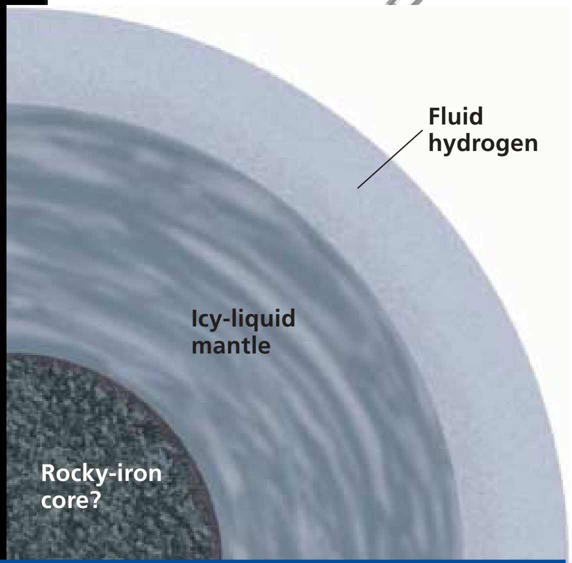




Uranus	
Diameter	51,120 km, or 4 times Earth's diameter
Density	1.30 g/cm^3, or 24% of Earth's density
Surface gravity	91% of Earth's surface gravity

Figure 5 ▶ This exaggerated-color image from the *Hubble Space Telescope* shows Uranus, two of its moons, and some of its rings.

Uranus

Uranus, shown in **Figure 5,** is the seventh planet from the sun and the third-largest planet in the solar system. Sir William Herschel discovered Uranus in 1781. Because Uranus is nearly 3 billion kilometers from the sun, Uranus is a difficult planet to study. But the *Hubble Space Telescope* has taken images that show changes in Uranus's atmosphere. Uranus has at least 24 moons and at least 11 thin rings. Its orbital period is almost 84 years.

Uranus's Rotation

The most distinctive feature of Uranus is its unusual orientation. Most planets, including Earth, rotate with their axes perpendicular to their orbital planes as they revolve around the sun. However, Uranus's axis is almost parallel to the plane of its orbit. The rotation rate of Uranus was not discovered until 1986, when *Voyager 2* passed by Uranus. Astronomers were then able to determine that Uranus rotated once about every 17 h.

Uranus's Atmosphere

Like the other gas giants, Uranus has an atmosphere that contains mainly hydrogen and helium. The blue-green color of Uranus indicates that the atmosphere also contains significant amounts of methane. The average cloud-top temperature of Uranus is –214°C. However, astronomers believe that the planet's temperature is much higher below the clouds. There may be a mixture of liquid water and methane beneath the atmosphere. Scientists also think that the center of Uranus, which has a temperature of about 7,000°C, is a core of rock and melted elements.

Neptune

Neptune, shown in **Figure 6,** is the eighth planet from the sun and is similar to Uranus in size and mass. Neptune's orbital period is nearly 164 years, and the planet rotates about every 16 h. Neptune has at least eight moons and possibly four rings.

The Discovery of Neptune

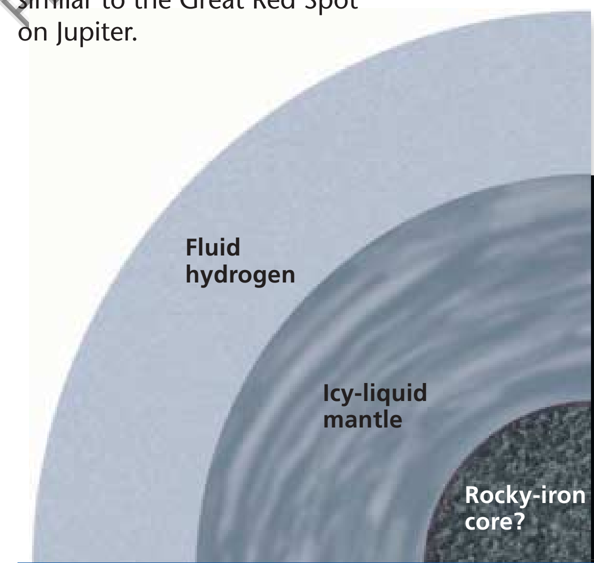
Neptune's existence was predicted before Neptune was actually discovered. After Uranus was discovered, astronomers noted variations from its calculated orbit. They suspected that the gravity of an unknown planet was responsible for the variation. In the mid-1800s, John Couch Adams, an English mathematician, and Urbain Leverrier, a French astronomer, independently calculated the position of the unknown planet. A German astronomer, Johann Galle, discovered a bluish-green disk where Leverrier had predicted the planet would be. Astronomers named the planet Neptune after the Roman god of the sea.

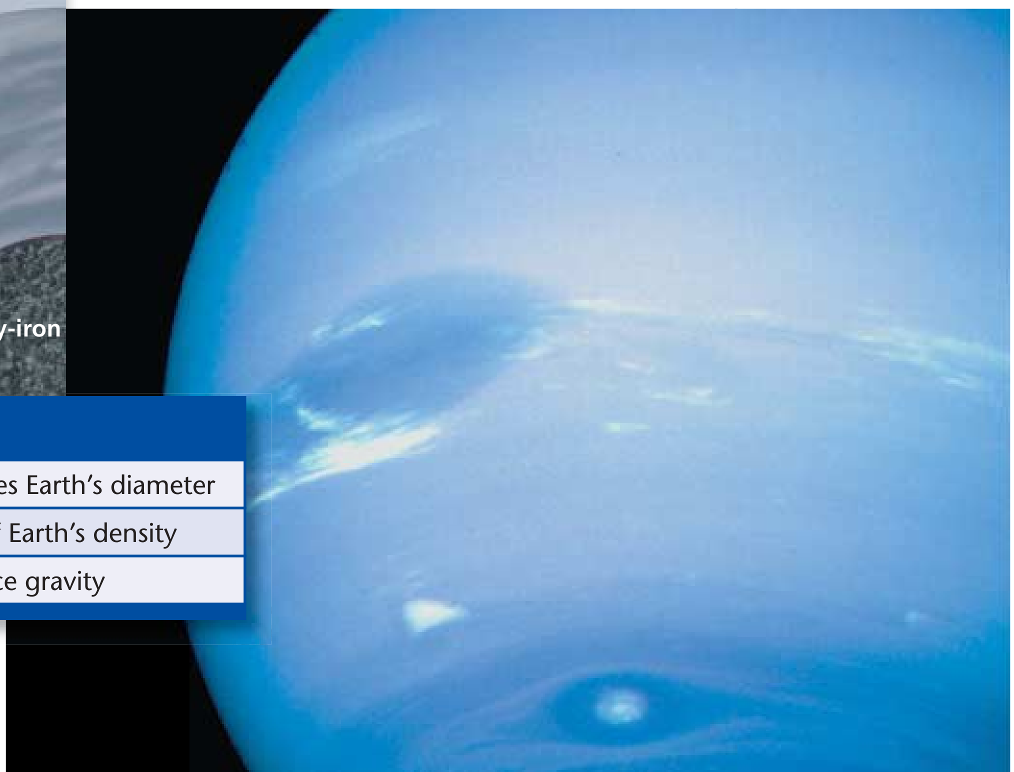
Neptune's Atmosphere

Data from the *Voyager 2* spacecraft indicate that Neptune's atmosphere is made up mostly of hydrogen, helium, and methane. Neptune's upper atmosphere contains some white clouds of frozen methane. These clouds appear as continually changing bands between the equator and the poles of Neptune.

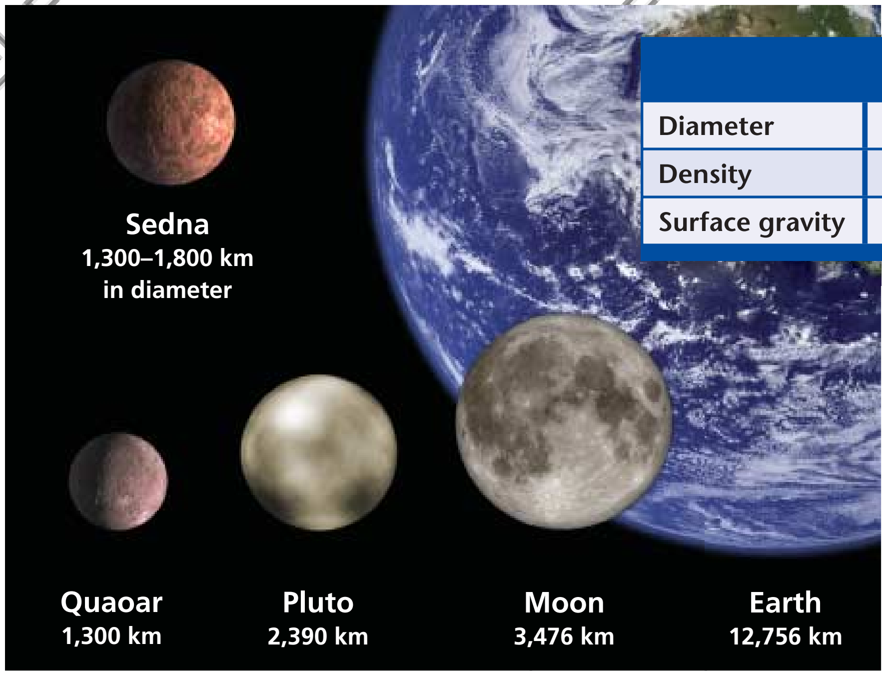
Images taken by *Voyager 2* and the *Hubble Space Telescope* indicate that Neptune has an active weather system. Neptune has the solar system's strongest winds, which exceed 1,000 km/h. A storm that is the size of Earth and that is known as the Great Dark Spot appeared and disappeared on Neptune's surface. Neptune's average cloud-top temperature is about –225ºC.

Figure 6 ▶ This Great Dark Spot on Neptune was a giant storm that was similar to the Great Red Spot on Jupiter.





Neptune	
Diameter	49,530 km, or 3.9 times Earth's diameter
Density	1.76 g/cm^3, or 32% of Earth's density
Surface gravity	1.2 times Earth's surface gravity



Pluto	
Diameter	2,390 km, or 20% of Earth's diameter
Density	2.1 g/cm^3, or 40% of Earth's density
Surface gravity	1% of Earth's surface gravity

Figure 7 ▶ Pluto, the smallest planet in our solar system, is even smaller than our moon. Quaoar and Sedna, as shown by these artist renditions, have a smaller diameter than Pluto and are not classified as planets.

Pluto

Pluto, as shown in **Figure 7,** the ninth planet from the sun, was discovered in 1930. Pluto orbits the sun in an unusually elongated and tilted ellipse. Pluto is sometimes inside the orbit of Neptune but is usually far beyond it. Having a diameter of 2,390 km, Pluto is the smallest planet in the solar system. It is also the farthest planet from the sun. Scientists think that Pluto is made up of frozen methane, rock, and ice. The planet has an average temperature of –235°C. Infrared images show that Pluto has extensive methane icecaps and a very thin nitrogen atmosphere. Pluto's only moon, Charon, is half the size of Pluto.

Objects Beyond Pluto

In recent years, scientists have discovered hundreds of objects in our solar system beyond Neptune's orbit. This region of the solar system, which contains these small bodies that are made mostly of ice, is called the **Kuiper belt** (KIE puhr BELT). Some objects that have been found in the Kuiper belt, such as Quaoar, shown in **Figure 7,** are more than half of Pluto's size. If other objects that are larger than Pluto are found there, some scientists think that Pluto should no longer be classified as a planet.

One of the most distant objects in the solar system was found beyond the Kuiper belt in March 2004. This object, which is named after the Inuit goddess of the ocean, Sedna, is about three-fourths the size of Pluto. It is also 3 times farther from Earth than Pluto is. However, Sedna is not classified as a planet. Scientists continue to study Sedna to learn more about it.

Kuiper belt a region of the solar system that is just beyond the orbit of Neptune and that contains small bodies made mostly of ice

Reading Check **Where is the Kuiper belt located? (See the Appendix for answers to Reading Checks.)**

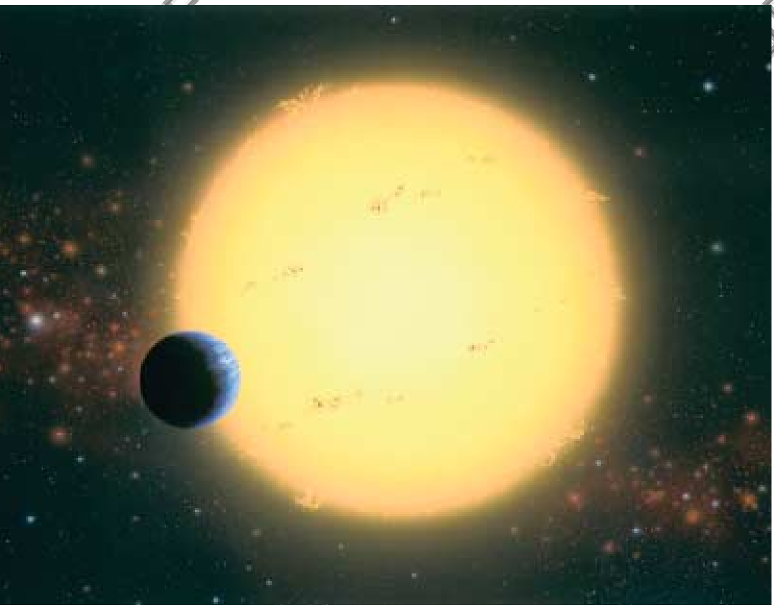


Figure 8 ▶ This illustration shows an artist's idea of a Jupiter-sized exoplanet that was recently discovered. This exoplanet orbits a sun-like star called HD209458, which is located 150 light years from Earth.

Exoplanets

Until the 1990s, all of the planets that astronomers had discovered were in Earth's solar system. Since then, however, more than 100 planets have been attributed to stars other than Earth's sun. Because these planets circle stars other than Earth's sun, they are called *exoplanets*. The prefix *exo-* means "outside." **Figure 8** shows an artist's rendition of an exoplanet. Most known exoplanets orbit stars that are similar to Earth's sun. Therefore, the existence of these planets leads some scientists to wonder if life could exist in another solar system.

Exoplanets cannot be directly observed with telescopes or satellites. Most exoplanets can be detected only because their gravity tugs on stars that they orbit. When scientists study some distant stars, they notice that the light coming from the stars shifts in wavelength. This shifting could be explained by the stars' movement slightly toward and then away from Earth. Scientists know that the gravity of an object that cannot be seen can affect a star's movement. In these cases, that object is most likely an exoplanet that orbits the star.

All of the exoplanets that have been identified are larger than Saturn because current technology can detect only large planets. Many of these exoplanets, though more massive than Jupiter, are closer to their stars than Mercury is to Earth's sun. From studying these many solar systems, scientists hope to learn more about the formation and basic arrangement of solar systems.

Section 4 Review

1. **Explain** what makes Jupiter similar to the sun.
2. **Compare** the characteristics of Jupiter, Saturn, Uranus, and Neptune.
3. **Compare** Jupiter's Great Red Spot with weather on Earth.
4. **Describe** the way in which the tilt of the axis of Uranus's rotation is unusual.
5. **Explain** how Pluto differs from the other outer planets.
6. **Summarize** the features of objects in the Kuiper belt.
7. **Describe** what scientists know about planets outside the solar system.

CRITICAL THINKING

8. **Making Comparisons** How are the compositions of the gas giants similar to the composition of the sun?
9. **Making Inferences** Why is Pluto considered the ninth planet from the sun even though Neptune is sometimes farther from the sun than Pluto is?
10. **Evaluating Conclusions** Should scientists still consider Pluto to be a planet? Explain your answer.

CONCEPT MAPPING

11. Use the following terms to create a concept map: *outer planet, Jupiter, Saturn, Uranus, Neptune, Pluto, gas giant, Kuiper belt,* and *Great Red Spot.*

Chapter 27 Highlights

Sections

1 Formation of the Solar System

Key Terms

solar system, 685
planet, 685
solar nebula, 685
planetesimal, 686

Key Concepts

- The solar system formed from a rotating and contracting region of gas and dust about 5 billion years ago.
- The planets formed from collisions of smaller bodies called *planetesimals*.
- As Earth cooled, differentiation caused three distinct compositional layers—the crust, the mantle, and the core—to form.

2 Models of the Solar System

eccentricity, 692
orbital period, 693
inertia, 694

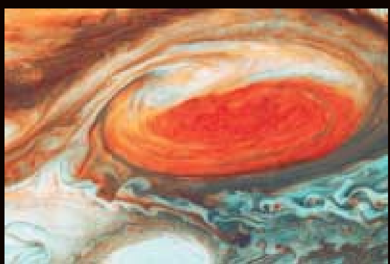
- Geocentric models of the solar system, such as those developed by Aristotle and Ptolemy, were replaced by the heliocentric model proposed by Copernicus.
- Kepler's three laws describe the motion of the planets in their orbits around the sun.
- The planets travel in elliptical orbits around the sun. Planets nearer to the sun travel faster than those farther from the sun do.

3 The Inner Planets

terrestrial planet, 695

- The four inner planets share similar characteristics and are called the *terrestrial planets*. Earth, Venus, and Mars have a history of geologic activity.
- The terrestrial planets are denser and smaller than the gas giants.

4 The Outer Planets



gas giant, 701
Kuiper belt, 707

- The outer planets consist of the four *gas giants*—Jupiter, Saturn, Uranus, and Neptune—and Pluto, which is the smallest, outermost planet in the solar system.
- The Kuiper belt is a region of the solar system that is beyond Neptune's orbit and that contains small bodies made mostly of ice.
- Exoplanets orbit stars other than the sun.

Chapter 27 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *inertia*
2. *terrestrial planet*
3. *Kuiper belt*

For each pair of terms, explain how the meanings of the terms differ.

4. *Kuiper belt* and *orbital period*
5. *planet* and *planetismal*
6. *terrestrial planet* and *gas giant*
7. *solar nebula* and *solar system*

Understanding Key Concepts

8. Copernicus's model of the solar system is
   a. geocentric. **b.** lunocentric. **c.** ethnocentric. **d.** heliocentric.

9. Kepler's first law states that each planet orbits the sun in a path called a(n)
   a. ellipse. **b.** circle. **c.** epicycle. **d.** period.

10. The most distinctive feature of Jupiter is its
    a. Great Red Spot. **b.** Great Dark Spot. **c.** ring. **d.** elongated orbit.

11. The planet that has an axis of rotation that is almost parallel to the plane of its orbit is
    a. Venus. **b.** Jupiter. **c.** Uranus. **d.** Neptune.

12. The tilt of the axis of Mars is nearly the same as that of
    a. Mercury. **b.** Venus. **c.** Earth. **d.** Jupiter.

13. The planet that rotates faster than any other planet in the solar system is
    a. Earth. **b.** Jupiter. **c.** Uranus. **d.** Pluto.

14. Kepler's law that describes how fast planets travel at different points in their orbits is called the law of
    a. ellipses. **b.** equal speeds. **c.** equal areas. **d.** periods.

15. All of the outer planets in the solar system are large *except*
    a. Saturn. **b.** Uranus. **c.** Nepture. **d.** Pluto.

16. The first atmosphere of Earth was made mostly of
    a. helium. **b.** oxygen. **c.** carbon dioxide. **d.** methane.

17. The hypothesis that states that the sun and the planets developed out of the same cloud of gas and dust is called the
    a. Copernicus hypothesis.
    b. solar hypothesis.
    c. nebular hypothesis.
    d. Galileo hypothesis.

18. In the process of photosynthesis, green plants give off
    a. hydrogen. **b.** oxygen. **c.** carbon dioxide. **d.** helium.

Short Answer

19. Explain how Earth's early atmosphere differs from Earth's atmosphere today.
20. What is the shape of the planets' orbits?
21. What is Kepler's first law?
22. How did Newton's ideas about the orbits of the planets differ from Kepler's ideas?
23. List three features of Earth that allow it to sustain life.
24. Describe how a planet might form.
25. How did differentiation help to form solid Earth?

Critical Thinking

26. Applying Ideas Suppose astronomers discover that exoplanets orbiting stars that are similar to Earth's sun have similar compositions to the planets in Earth's solar system. What can the astronomers hypothesize about the formation of those solar systems?

27. Identifying Trends If you know the distance from the sun to a planet, what other information can you determine about the orbit of the planet? Explain your answer.

28. Making Inferences How would the layers of Earth be different if the planet had never been hotter than it is today?

Concept Mapping

29. Use the following terms to create a concept map: *solar system, planet, protoplanet, planetesimal, differentiation, core, mantle, crust, geocentric, heliocentric, Aristotle, Ptolemy, Copernicus, ellipse, Earth, terrestrial planet, outer planet, Jupiter, Pluto, gas giant, Kuiper belt, solar nebula* and *inner planet*.

Math Skills

30. Making Calculations Mercury has a period of rotation equal to 58.67 Earth days. Mercury's period of revolution is equal to 88 Earth days. How many times does Mercury rotate during one revolution around the sun?

31. Applying Quantities Uranus's orbital period is 84 years. What is its distance from the sun in astronomical units?

32. Making Calculations Venus's orbital period is 225 days. Calculate your age in Venus years.

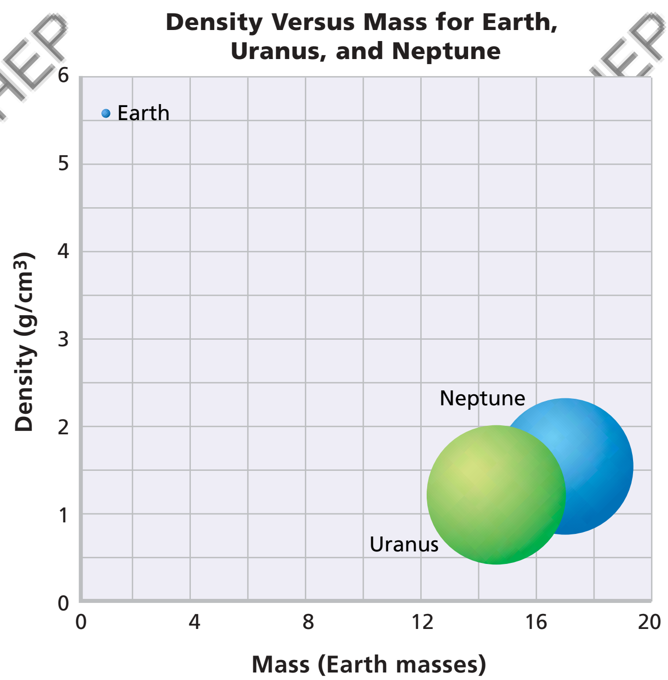
Writing Skills

33. Creative Writing Imagine that you are the first astronaut to land on Mars. In a short essay, describe what you hope and expect to find.

34. Communicating Main Ideas Create your own definition for *planet*. Then, write an explanation for why Pluto is or is not a planet.

Interpreting Graphics

The graph below shows density in relation to mass for Earth, Uranus, and Neptune. Mass is given in Earth masses. The mass of Earth is equal to 1. Use the graph to answer the questions that follow:



35. Which planet is denser, Uranus or Neptune? Explain your answer.

36. Which planet has the smallest mass?

37. How can Earth be the densest of the three planets even though Uranus and Neptune have so much more mass than Earth does?

8099

Chapter 27 Standardized Test Prep

Understanding Concepts

***Directions (1–5):* For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 Small bodies that join to form protoplanets in the early stages of the development of the solar system are
- **A.** planets
- **B.** solar nebulas
- **C.** plantesimals
- **D.** gas giants

2 Scientists hypothesize that Earth's first oceans were made of fresh water. How did oceans obtain fresh water?
- **F.** Water vapor in the early atmosphere cooled and fell to Earth as rain.
- **G.** Frozen comets that fell to Earth melted as they traveled through the atmosphere.
- **H.** As soon as icecaps formed, they melted because Earth was still very hot.
- **I.** Early terrestrial organisms exhaled water vapor, which condensed to form fresh water.

3 The original atmosphere of Earth consisted of
- **A.** nitrogen and oxygen gases
- **B.** helium and hydrogen gases
- **C.** ozone and ammonia gases
- **D.** oxygen and carbon dioxide gases

4 Scientists think that the core of Earth is made of molten
- **F.** iron and nickel
- **G.** nickel and magnesium
- **H.** silicon and nickel
- **I.** iron and silicon

5 Scientists estimate that the sun originated as a solar nebula and began to produce its own energy through nuclear fusion approximately how many years ago?
- **A.** 50 million years
- **B.** 500 million years
- **C.** 1 billion years
- **D.** 5 billion years

***Directions (6–7):* For *each* question, write a short response.**

6 What four planets make up the group known as the inner planets?

7 The Great Red Spot is found on what planet?

Reading Skills

***Directions (8–10):* Read the passage below. Then, answer the questions.**

Movement of the Planets

Imagine that it is the year 200 BCE and that you are an apprentice to a famous Greek astronomer. After many years of observing the sky, the astronomer knows all of the constellations as well as he knows the back of his hand. He shows you how all the stars move together—how the whole sky spins slowly as the night goes on. He also shows you that among the thousands of stars in the sky, some of the brighter ones slowly change their position in relation to the other stars. The astronomer names these stars plantetai, the Greek word that means "wanderers."

Building on the observations of the ancient Greeks, we now know that the planetai are actually planets, not wandering stars. Because of their proximity to Earth and their orbits around the sun, the planets appear to move relative to the stars.

8 According to the passage, which of the following statements is not true?
- **A.** It is possible to determine planets in the night sky by the way they move relative to the other stars.
- **B.** The word planetai means "wanderers" in the Greek language.
- **C.** Some of the earliest astronomers to detect the presence of planets were Roman.
- **D.** Ancient Greeks were studying astronomy more than 2,200 years ago.

9 What can you infer from the passage about the ancient Greek astronomers?
- **F.** They were patient and observant.
- **G.** They knew much more about astronomy than we do today.
- **H.** They spent all of their time counting the number of stars in the sky.
- **I.** They invented astronomy and were the first people to observe the skies.

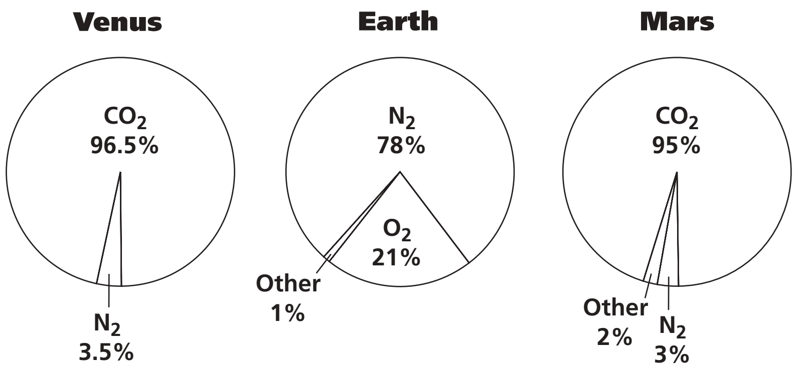
10 What did the Greek astronomers note about the movement of stars and constellations?

Interpreting Graphics

Directions (11–14): **For *each* question below, record the correct answer on a separate sheet of paper.**

The pie graphs below show the percentages of different gases in the atmospheres of three planets. Use these graphs to answer questions 11 and 12.

Atmospheres of Venus, Earth, and Mars



11 What is the percentage of carbon dioxide in the atmosphere of Venus?

A. 3.5%
B. 21%
C. 95%
D. 96.5%

12 Today, Earth's atmosphere includes a large amount of oxygen. Describe how the oxygen in Earth's atmosphere formed, and using this information, predict the likelihood that Mars will someday have oxygen in its atmosphere.

The table below shows the orbital and rotational periods of the first five planets in the solar system. Use this table to answer questions 13 and 14.

Planets of the Solar System

Planet	Orbital period	Rotational period
Mercury	88 days	59 days
Venus	225 days	243 days
Earth	365.25 days	23 hours 56 minutes
Mars	687 days	24 hours 37 minutes
Jupiter	12 years	9 hours 50 minutes
Saturn	29.5 years	10 hours 30 minutes
Uranus	84 years	17 hours
Neptune	164 years	16 hours
Pluto	248 years	153 hours 20 minutes

13 Which planet's day length is nearly the same as Earth's?

F. Mercury
G. Mars
H. Saturn
I. Neptune

14 How many rotations does Neptune complete in one Earth day?

Test TIP

Even if you are sure of the answer to a test question, read all of the answer choices before selecting your response.

Objectives

- **Create** a model that demonstrates the formation of impact craters.
- USING SCIENTIFIC METHODS **Analyze** how an object's speed and projectile angle affect the impact crater that the object forms on planets and moons.

Materials

- marble, large (1)
- marbles, small (5)
- marker
- meter stick
- plaster of Paris
- protractor
- scissors
- shoe box
- tape, masking
- toothpicks (6)
- tweezers

Safety

Crater Analysis

All of the inner planets—Mercury, Venus, Earth, and Mars—have many features in common. They are made of mostly solid rock and have metallic cores. They have no rings and have from zero to two moons each. And they have bowl-shaped depressions called *impact craters*. Impact craters are caused by collisions between the planets and rocky objects that travel through space. Most of these collisions took place during the formation of the solar system.

Mercury's entire surface is covered with these craters, while very few craters are still evident on the surface of Earth. Many of the moons of the inner and outer planets are also heavily cratered. In this lab, you will experiment with making craters to discover the effect of speed and projectile angle on the way craters form.

PROCEDURE

1. Place the top of a toothpick in the center of a piece of masking tape that is 6 cm long. Fold the tape in half around the toothpick to form a "small flag" and "flagpole." On the flag, write the letter *A*. Repeat this step for the other toothpicks, and label them with the letters *B* through *F*.

Step 7

2 Mix plaster of Paris with water, according to instructions for making plaster of Paris. Spread your mixture in the bottom of the shoe box. Make your plaster layer about 4 cm thick. The surface should be as smooth as possible.

3 Allow the plaster to dry until it is no longer soupy, but not yet rigid.

4 Drop a large marble onto the plaster from a height of 50 cm above the surface. Quickly remove the marble with tweezers, but do not damage the crater that formed. Place flag A next to the crater to label the crater.

5 Repeat **step 4** by using a small marble dropped from a height of 50 cm and another small marble dropped from a height of 25 cm. Use the flags to label craters *B* (50 cm drop) and *C* (25 cm drop).

Step 6

6 Repeat **step 4** by using a small marble dropped from a height of 1 m. Label the crater *D*.

7 Using a protractor as a guide, have your partner tilt the box at a 30° angle to the table. Be sure your partner holds the box steady. Then, drop a small marble vertically from a height of 50 cm. Label the crater *E*.

8 Repeat **step 7** by using an angle of 45°. Label the crater *F*.

9 Allow the plaster of Paris to harden. Write a description of each crater and the surrounding area.

ANALYSIS AND CONCLUSION

1 **Examining Data** Which crater was formed by the marble that had the highest velocity? What is the effect of velocity on the characteristics of the crater formed?

2 **Explaining Events** Study the shapes of craters B, E, and F. How did the angle of the plaster of Paris affect the shape of the craters that formed?

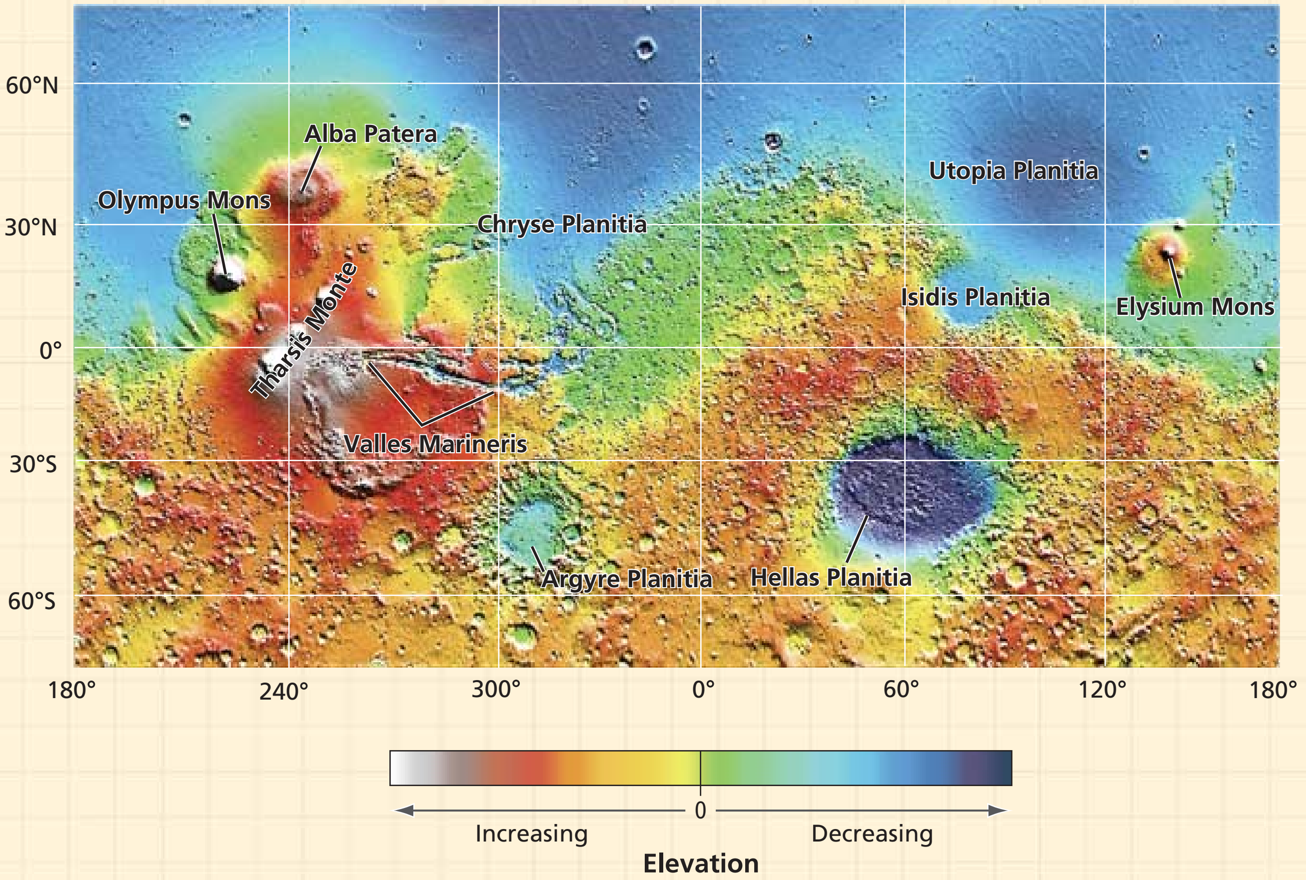
3 **Making Comparisons** Compare craters A, B, and D. How do they differ from each other? What caused this difference? Is the difference in the masses of the objects a factor? Explain your answer.

Extension

1 **Applying Conclusions** Find a map of the surface craters on one of the terrestrial planets. Identify craters that were made by different angles of impact. Label the craters on the diagram, and present your findings to the class.

MAPS in Action

MOLA Map of Mars



Map Skills Activity

The above map shows the relative elevation of surface features on Mars's surface. The number 0 on the elevation scale marks the average elevation at the equator. This map was created from data that was collected by the Mars Orbiter Laser Altimeter (MOLA) on the *NASA Mars Global Surveyor*. Use the map to answer the questions below.

1. **Analyzing Data** Estimate the longitude and latitude of Elysium Mons.
2. **Using the Key** Identify three features that have elevations below 0. Identify three features that have elevations above 0.
3. **Comparing Areas** In general, which pole on Mars, the north pole or south pole, has higher elevations?
4. **Using the Key** Which feature, Isidis Planitia or Argyre Planitia, has a higher elevation?
5. **Making Comparisons** Which feature, Hellas Planitia or Olympus Mons, would most likely be a volcano?
6. **Using the Key** Estimate the distance between Olympus Mons and Elysium Mons in degrees of longitude.
7. **Inferring Relationships** Based on what you have learned from the map, what type of features do you think the words *planitia,* and *mons* refer to?

Astronomer

"As a five-year-old, I had binoculars—I'd lie on the lawn at night and use them to look at the sky," says Sandra Faber, professor of astronomy at the University of Santa Cruz, and staff member at the Lick Observatory in Santa Cruz, California.

Like a Detective Story

Faber's research focuses on the formation and evolution of galaxies and the evolution of structures in the universe. To gather data, Faber uses various kinds of telescopes, including ground-based telescopes and the *Hubble Space Telescope*. "Astronomy is like a big detective story," she says. "Information is gathered and shared among scientists, who then draw scientific conclusions about how the universe came to be." Faber is currently a core member of the Deep Extragalactic Evolutionary Probe (DEEP) project. DEEP uses the Keck II telescope in Hawaii and the *Hubble Space Telescope* to survey faint, faraway galaxies.

A Look Back in Time

To see these galaxies, the DEEP project uses a spectrographic instrument called DEIMOS, which stands for *deep imaging multi-object spectrograph*. DEIMOS allows Faber and her colleagues to collect and analyze light that has traveled for billions of years from its original source. Astronomers call such research *look back studies*. By collecting data, Faber can look back billions of years to find answers to scientific questions about the origin of the universe.

Faber's research has given her appreciation for Earth's uniqueness. She says, "Earth is far more varied and beautiful than any other planet. It's all we've got." She also has a special perspective on the Earth's vulnerability: "When seen from space, the Earth is small. It floats in a hostile void. Its atmosphere is thin, like the skin on an apple. Even from space, one can see visual signs of pollutants. It provides a motivation for humans to save this planet and take advantage of its enormous possibilities." In many ways, notes Faber, "Earth is like a spaceship. It's up to the crew members to maintain control."

"Astronomy offers profound messages for our future. It provides a motivation for humans to save this planet and take advantage of its enormous possibilities."

—Sandra Faber

◀ Faber studies distant galaxies from the W. M. Keck Observatory on top of the Hawaiian volcano Mauna Kea.

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Chapter 28 Minor Bodies of the Solar System

Sections

Earth's Moon

Movements of the Moon

Satellites of Other Planets

Asteroids, Comets, and Meteoroids

What You'll Learn

- What Earth's moon is made of and how it moves
- How satellites of other planets differ from Earth's moon
- What comets, asteroids, and meteoroids are

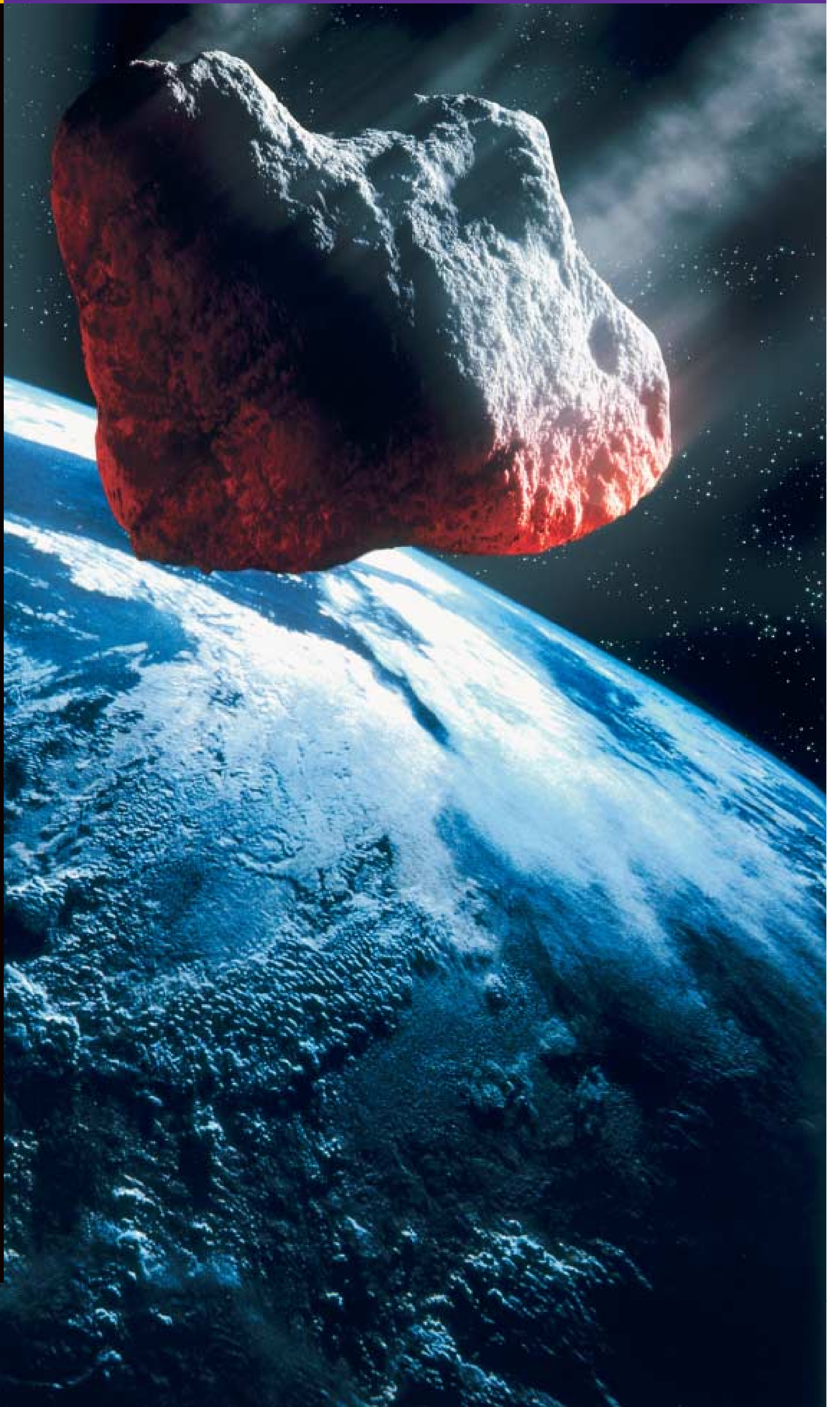
Why It's Relevant

Small orbiting objects can provide information about the conditions that existed at the beginnings of our solar system.

PRE-READING ACTIVITY

FOLDNOTES

Booklet Before you read this chapter, create the FoldNote entitled "Booklet" described in the Skills Handbook section of the Appendix. Label each page of the booklet with a main idea from the chapter. As you read the chapter, write what you learn about each main idea on the appropriate page of the booklet.



▶ This is one idea of how an asteroid might look as it moves toward Earth. Asteroids are one type of small body that travels through our solar system.

Section 1 Earth's Moon

A body that orbits a larger body is called a **satellite.** Seven of the planets in our solar system have smaller bodies that orbit around them. These natural satellites are also called **moons.** Our moon is Earth's natural satellite.

In 1957, the Soviet Union launched *Sputnik 1,* which was the first *artificial satellite* launched into space. In 1958, the United States launched its first artificial satellite, which was named *Explorer 1*. Thousands of artificial satellites are now in orbit around Earth, including weather satellites and space telescopes, such as the *Hubble Space Telescope*.

OBJECTIVES

- **List** four kinds of lunar surface features.
- **Describe** the three layers of the moon.
- **Summarize** the three stages by which the moon formed.

KEY TERMS

satellite
moon
mare
crater

Exploring the Moon

Between 1969 and 1972, the United States sent six spacecraft to the moon as part of the Apollo space program. Apollo astronauts found that the moon's weak gravity affected the way they moved. They discovered that bouncing was more efficient than walking. Apollo astronauts also explored the moon's surface in a variety of specially-designed vehicles, such as the one shown in **Figure 1.**

The moon has much less mass than Earth does, so the gravity experienced on the moon's surface is about one-sixth of the gravity experienced on Earth. As a result, a person who has a mass of 61.2 kg and who exerts about 600 newtons (N) of force on Earth would exert only about 100 N on the moon. The gravity at the moon's surface is not strong enough to hold gases and therefore has no atmosphere. Because the moon has no atmosphere to absorb and transport heat, the moon's surface temperature varies greatly, from 134°C during the day to –170°C at night.

satellite a natural or artificial body that revolves around a planet

moon a body that revolves around a planet and that has less mass than the planet does

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Topic: Earth's Moon
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Figure 1 ▶ *Apollo 17* astronaut Eugene Cernan explores the lunar surface in a Lunar Roving Vehicle.

The Lunar Surface

Because *luna* is the Latin word for "moon," any feature of the moon is referred to as *lunar*. Light and dark patches on the moon can be seen with the unaided eye. The lighter areas are rough highlands that are composed of rocks called *anorthosites*. The darker areas are smooth, reflect less light, and are called *maria* (MAHR ee uh). Each dark area is a **mare** (MAHR AY). *Mare* is Latin for "sea." Galileo named these dark areas *maria* because he thought that they looked like Earth's seas. Today, astronomers know that maria are plains of dark, solidified lava. These lava plains formed more than 3 billion years ago when lava slowly filled basins that were created by impacts of massive asteroids.

mare a large, dark area of basalt on the moon (plural, *maria*)

crater a bowl-shaped depression that forms on the surface of an object when a falling body strikes the object's surface or when an explosion occurs

Craters, Rilles, and Ridges

The surface of the moon, shown in **Figure 2**, is covered with numerous bowl-shaped depressions, called **craters**. Most of the moon's craters formed when debris left over from the formation of the solar system struck the moon about 4 billion years ago. Younger craters are characterized by bright streaks, called *rays*, that extend outward from the impact site. Even these younger craters, however, are billions of years old.

Long, deep channels called *rilles* run through the maria in some places. The moon's rilles are thought to be leftover lava channels from the formation of the maria. Some rilles are as long as 240 km. Another surface feature of the moon is ridges. Ridges are long, narrow elevations of rock that rise out of the surface and criss-cross the maria.

Reading Check **Name two features of the moon. (See the Appendix for answers to Reading Checks.)**

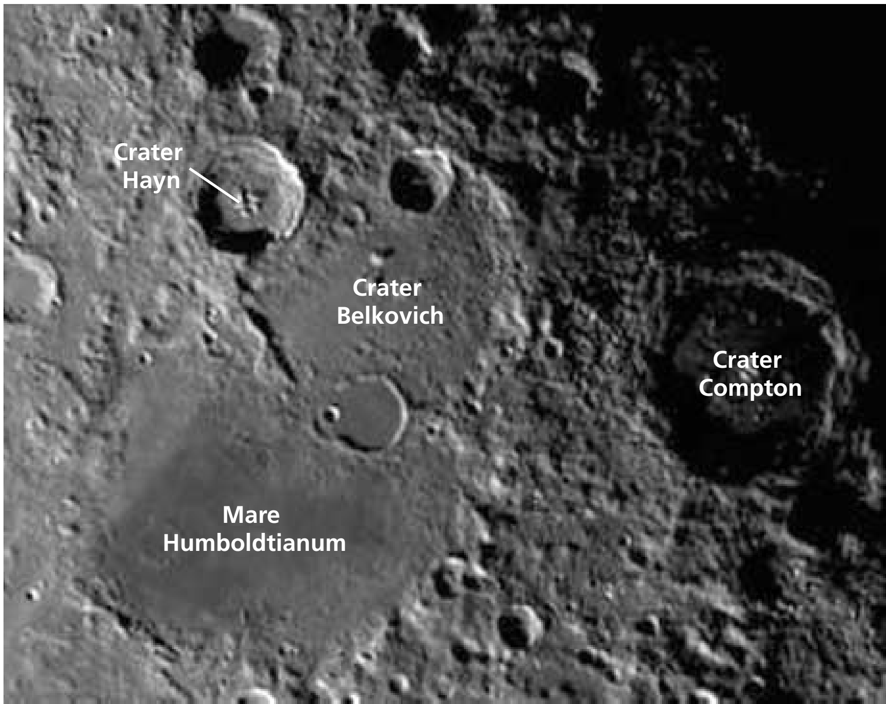


Figure 2 ▶ The largest lunar craters are named for famous scholars and scientists. The lunar surface also has millions of small, overlapping craters. ***How does the shape of Mare Humboldtianum indicate that this feature once was an impact crater?***

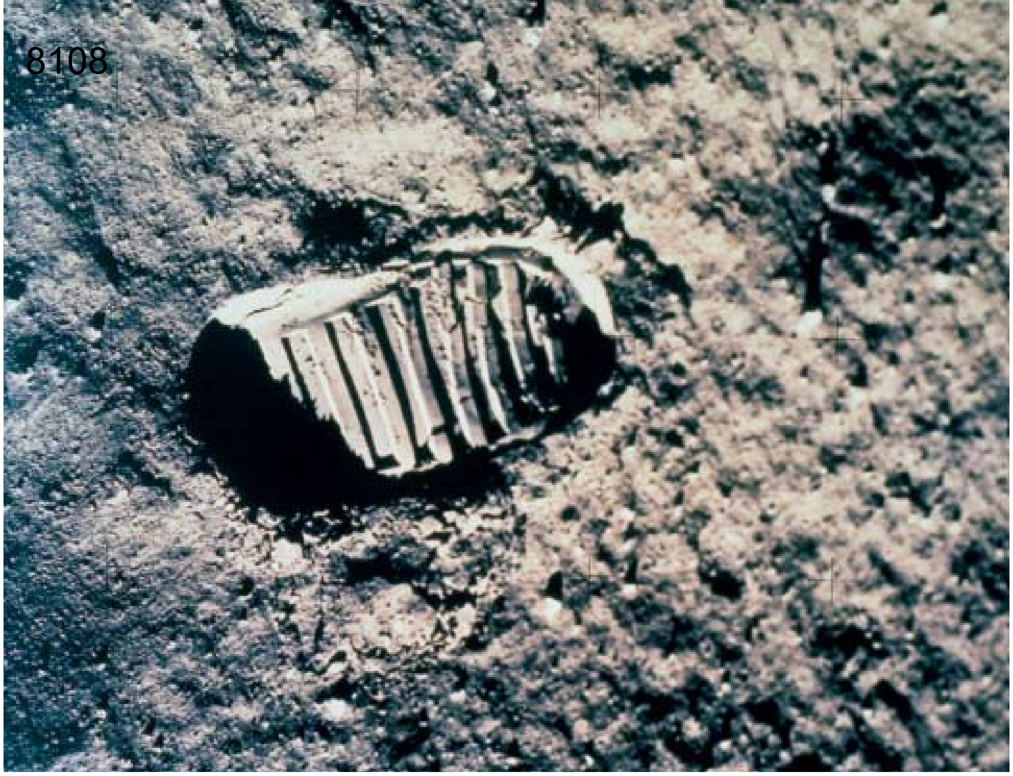


Figure 3 ▶ This footprint is one of the first marks left on the moon by humans. The footprint is visible because of the fine layer of rock and dust, called *regolith,* that covers the moon's surface.

Regolith

More meteorites have reached the surface of the moon than have reached Earth's surface because the moon has no atmosphere for protection. Over billions of years, these meteorites crushed much of the rock on the lunar surface into dust and small fragments. Today, almost all of the lunar surface is covered by a layer of dust and rock, called *regolith*. Regolith is shown in **Figure 3.** The depth of the regolith layer varies from 1 m to 6 m.

Lunar Rocks

Many lunar rocks are very similar to rocks on Earth. Lunar rocks, including the one shown in **Figure 4,** contain many of the same elements as Earth's rocks do, but lunar rocks contain different proportions of those elements. Lunar rocks are igneous, and most rocks near the surface are composed mainly of oxygen and silicon. These surface rocks are similar to the rocks in Earth's crust. Rocks from the lunar highlands are light-colored, coarse-grained anorthosites. Highland rocks are rich in calcium and aluminum. Rocks from the maria are fine-grained basalts and contain large amounts of titanium, magnesium, and iron.

Nevertheless, lunar surface rocks have only small amounts of some elements that are common on Earth. Many of these elements have low melting points and may have boiled off early in the moon's history when the moon was still molten. Also, the minerals in lunar rocks do not contain water.

One type of rock that occurs in both maria and the highlands is *breccia*. Lunar breccia contains fragments of other rocks that have been fused together. These breccias formed when meteorites struck the moon. The force of these impacts broke up rocks, and the heat from the impacts partially melted the fragments.

Figure 4 ▶ This rock is 4.3 billion to 4.5 billion years old; it is the oldest rock discovered on the moon. The rock's texture indicates that the rock has a complicated history.

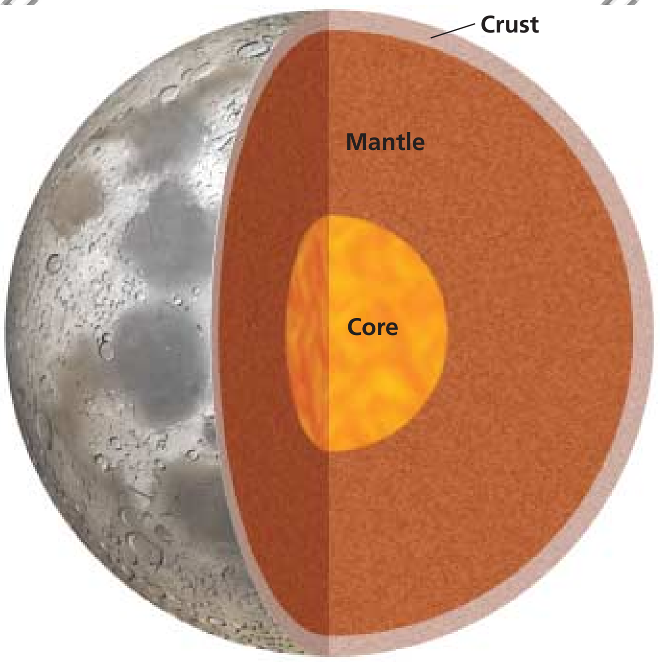


Figure 5 ▶ The moon, like Earth, has three compositional layers: the crust, the mantle, and the core.

The Interior of the Moon

Rocks of the lunar surface are about as dense as those on Earth's surface. However, the overall density of the moon is only three-fifths the density of Earth. The difference in overall density indicates that the interior of the moon is less dense than the interior of Earth.

Most of the information about the interior of the moon comes from seismographs that were placed on the moon by the Apollo astronauts. Seismographs have recorded numerous weak moonquakes, which are similar to earthquakes. More than 10,000 moonquakes have been detected. Most moonquakes occur in the mantle at a depth that is 10 times deeper than the depth at which most earthquakes occur on Earth. From these moonquakes, scientists learned that the moon's interior is layered, as shown in **Figure 5.**

The Moon's Crust

One side of the moon always faces Earth. That side is therefore called the *near side*. The other side always faces away from Earth and is called the *far side*. The pull of Earth's gravity during the moon's formation caused the crust on the far side of the moon to become thicker than the crust on the near side. On the near side, the lunar crust is about 60 km thick. On the far side, the lunar crust is up to 100 km thick. Images of the far side show that the far side's surface is mountainous and has only a few small maria. The crust of the far side appears to consist of materials that are similar to those of the rocks in the highlands on the near side.

Reading Check **Name two features of the far side of the moon. (See the Appendix for answers to Reading Checks.)**

The Moon's Mantle and Core

Beneath the crust is the moon's mantle. The mantle is thought to be made of rock that is rich in silica, magnesium, and iron. Of the moon's 1,738 km radius, the mantle makes up more than half of that distance and reaches 1,000 km below the crust.

Scientists think that the moon has a small iron core that has a radius of less than 700 km. When laser beams were bounced off of small mirrors placed on the moon, scientists discovered that the moon's rotation is not uniform. This non-uniform rotation indicates that the core is neither completely solid nor completely liquid. This characteristic may explain why the moon has almost no overall magnetic field. There are, however, small areas on the moon that exhibit local magnetism.

QuickLAB 5 min

Liquid and Solid Cores

Procedure

1. Take **one uncooked egg** and **one hardboiled egg.** With your thumb and forefinger, spin both eggs.
2. Record the amount of time each egg spins.
3. Lay **one can of solid food** and **one can of soup** on their sides, and spin both cans.
4. Record the amount of time each can spins.

Analysis

1. Which egg stopped spinning first? Which can of food stopped spinning first?
2. Which rotates more steadily: an object that has a solid core or an object that has a liquid core? Explain your answer.

The Formation of the Moon

Rocks taken from the moon by Apollo astronauts provided evidence to help astronomers understand the moon's history. Most scientists generally agree that the moon formed in three stages.

The Giant Impact Hypothesis

Most scientists think that the moon's development began when a large object collided with Earth more than 4 billion years ago. This *giant impact hypothesis* states that a Mars-sized body struck Earth early in the history of the solar system. Before the impact, Earth was molten, or heated to an almost liquid state. The collision ejected chunks of Earth's mantle into orbit around Earth. The debris eventually clumped together to form the moon, as shown in **Figure 6.**

Most of the ejected materials came from Earth's silica-rich mantle rather than from Earth's dense, metallic core. This hypothesis explains why moon rocks share many of the chemical characteristics of Earth's mantle. As the material clumped together, it continued to revolve around Earth because of Earth's gravitational pull.

Differentiation of the Lunar Interior

Early in its history, the lunar surface was covered by an ocean of molten rock. Over time, the densest materials moved toward the center of the moon and formed a small core. The least dense materials formed an outer crust. The other materials settled between the core and the outer layer to form the moon's mantle.

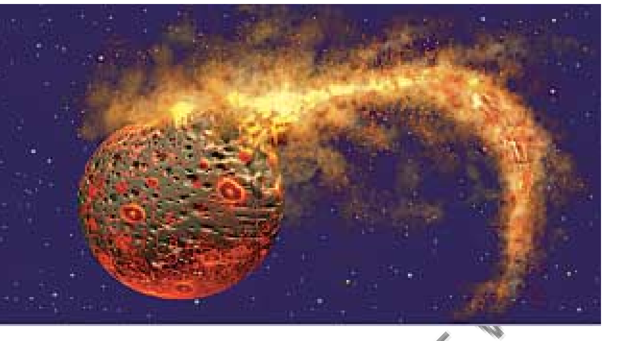
Meteorite Bombardment

The outer surface of the moon eventually cooled to form a thick, solid crust over the molten interior. At the same time, debris left over from the formation of the solar system struck the solid surface and produced craters and regolith.

About 3 billion years ago, the number of small objects in the solar system decreased. Less material struck the lunar surface, and few new craters formed. Craters that have rays formed during the most recent meteor impacts. During this stage of lunar development, virtually all geologic activity stopped. Because the moon cooled more than 3 billion years ago, it looks today almost exactly as it did 3 billion years ago. Therefore, the moon is a valuable source of information about the conditions that existed in the solar system long ago.

Figure 6 ▶ The First Stage of Moon Formation

Scientists think that a Mars-sized object collided with Earth and blasted part of Earth's mantle into space.



The resulting debris then began to revolve around Earth.

The material eventually joined to form Earth's moon.

Figure 7 ▶ The near side of the moon (top) has fewer visible craters than the far side (bottom) does because lava flows on the near side covered many of the impact sites with maria.

Lava Flows on the Moon

After impacts on the moon's surface formed deep basins, lava flowed out of cracks, or *fissures*, in the lunar crust. This lava flooded the crater basins to form maria. The presence of the maria suggests that fissure eruptions once characterized the moon, even though there is no evidence that active volcanoes have ever been present on the moon.

Because the moon's crust is thinner on the near side than on the far side, much more lava flowed onto the surface on the near side than onto the surface of the far side of the moon. The near side of the moon has several smooth maria, but the far side has few maria and many more craters, as shown in **Figure 7.**

Scientists do not yet know how magma formed in the lunar interior or how the magma reached the surface. There is no evidence of plate tectonics or convection currents in the moon's mantle, so the magma must have formed in some other way. A large amount of energy would have been needed to produce the magma in the upper layers of the moon. Some scientists think this energy may have come from a long period of intense meteorite bombardment. Other scientists think that radioactive decay of materials may have also heated the moon's interior enough to cause magma to form. Scientists agree that the lava flows ended about 3.1 billion years ago, when the interior cooled completely.

Section 1 Review

1. **Describe** what maria on the surface of the moon look like and how they came to be known as maria.
2. **Compare** the thickness of the moon's crust on the near side with the thickness of the crust on the far side.
3. **Summarize** how and when the maria formed.
4. **Describe** how the surface of the moon would be different today if meteorites had continued to hit it at the same rate as they did 3 billion years ago.
5. **Describe** breccias and how they formed on the moon.
6. **Summarize** how scientists think the moon formed.

CRITICAL THINKING

7. **Analyzing Ideas** Explain how Earth's gravity affected the moon's near side and far side differently.
8. **Making Comparisons** Compare the features of the lunar surface created by lava flows and the features created by impacts.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *moon, meteorite, crater, rille, maria, highlands,* and *basalt.*

Section 2 Movements of the Moon

If you looked down on the moon from above its north pole, you would see the moon rotate once on its axis every 27.3 days. However, if you stood on the moon's surface and measured the lunar day by the amount of time between sunrises, you would find that a lunar day is 29.5 Earth days long. This discrepancy is due to the fact that, while the moon is revolving around Earth, Earth and the moon are also revolving around the sun.

OBJECTIVES

- **Describe** the shape of the moon's orbit around Earth.
- **Explain** why eclipses occur.
- **Describe** the appearance of four phases of the moon.
- **Explain** how the movements of the moon affect tides on Earth.

KEY TERMS

apogee
perigee
eclipse
solar eclipse
lunar eclipse
phase

The Earth-Moon System

To observers on Earth, the moon appears to orbit Earth. However, if you could observe Earth and the moon from space, you would see that Earth and the moon revolve around each other. Together, they form a single system that orbits the sun.

The mass of the moon is only 1/80 that of Earth. So, the balance point of the Earth-moon system is not halfway between the centers of the two bodies. The balance point is located within Earth's interior because Earth's mass is greater than the moon's mass. This balance point is called the *barycenter*. The barycenter follows a smooth orbit around the sun, as shown in **Figure 1.**

The Moon's Elliptical Orbit

The orbit of the moon around Earth forms an ellipse that is about 5% more elongated than a circle is. Therefore, the distance between Earth and its moon varies over a month's time. When the moon is farthest from Earth, the moon is at **apogee.** When the moon is closest to Earth, the moon is at **perigee.** The average distance of the moon from Earth is 384,000 km.

apogee in the orbit of a satellite, the point at which the satellite is farthest from Earth

perigee in the orbit of a satellite, the point at which the satellite is closest to Earth

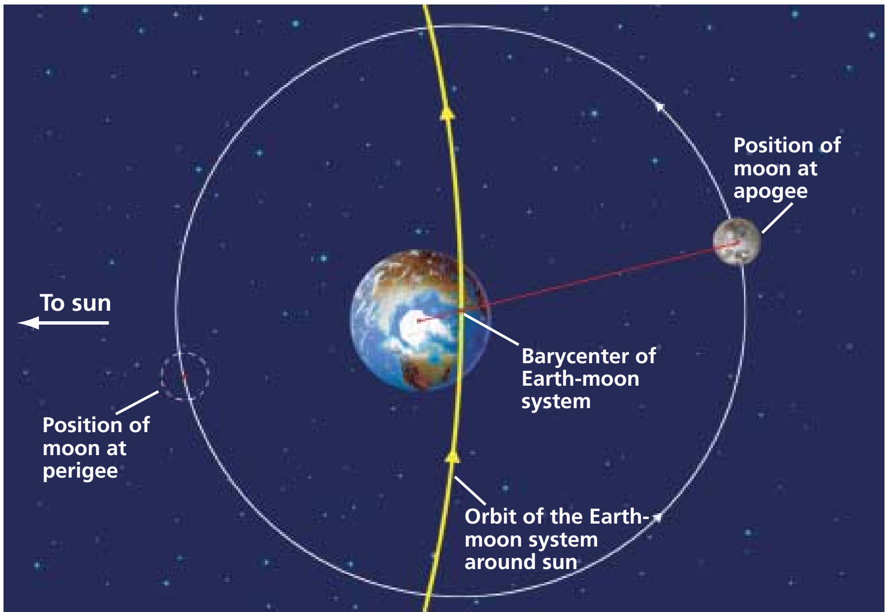


Figure 1 ▶ The barycenter of the Earth-moon system orbits the sun in a smooth ellipse. The orbits of both Earth and the moon "wobble" as the bodies move around the sun. This diagram is not to scale.

Moonrise and Moonset

The moon appears to rise and set at Earth's horizon because of Earth's rotation on its axis. If you were to watch the moon rise or set on successive nights, however, you would notice that it rises or sets approximately 50 minutes later each night. This happens because of both Earth's rotation and the moon's revolution. While Earth completes one rotation each day, the moon also moves in its orbit around Earth. It takes an extra 1/29 of Earth's rotation, or 50 minutes, for the horizon to catch up to the moon.

Lunar Rotation

In addition to orbiting Earth and revolving around the sun, the moon also spins on its axis. The moon rotated rapidly when it formed, but the pull of Earth's gravity has slowed the moon's rate of rotation. The moon now spins very slowly and completes a rotation only once during each orbit around Earth. The moon revolves only once around Earth in about 27.3 days relative to the stars. Because the rotation and the revolution of the moon take the same amount of time, observers on Earth always see the same side of the moon. Therefore, images of the far side of the moon must be taken by spacecraft orbiting the moon.

As the moon orbits Earth, the part of the moon's surface that is illuminated by sunlight changes. The sun's light always illuminates half of the moon and half of Earth, as shown in **Figure 2.** The near side of the moon is sometimes fully illuminated by the sun. At other times, depending on where the moon is in its orbit, the near side is partly or completely darkened.

Reading Check **Why are we unable to photograph the far side of the moon from Earth? (See the Appendix for answers to Reading Checks.)**

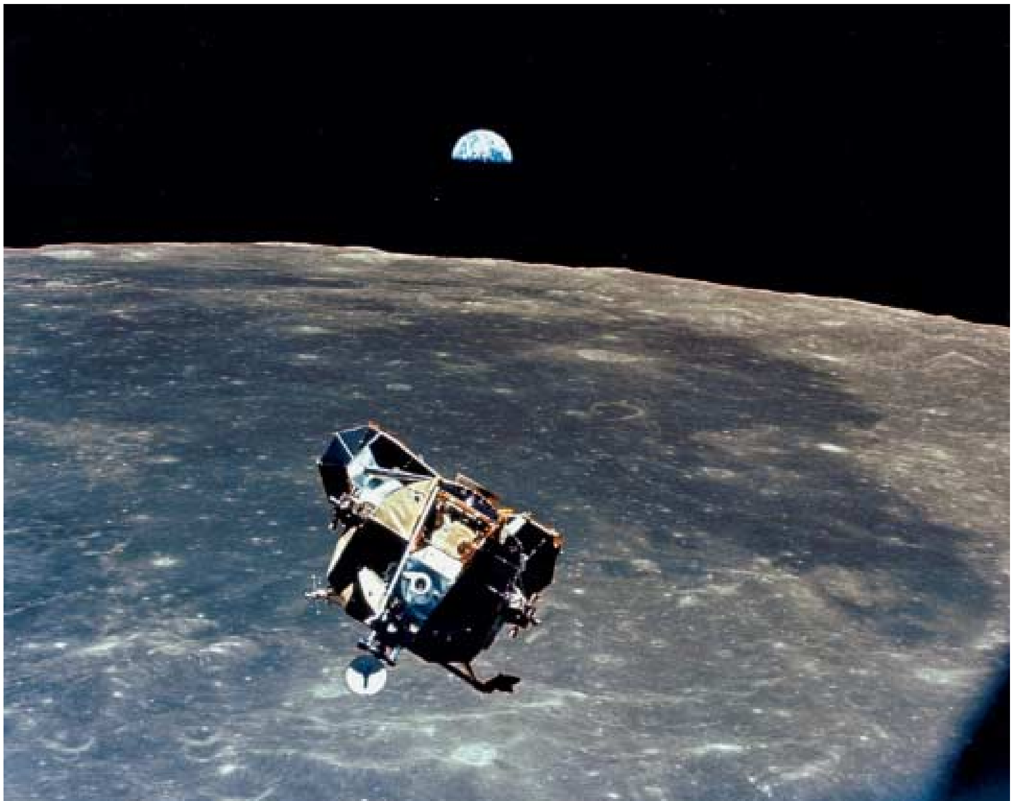


Figure 2 ▶ The lunar landing module, which was also called *The Eagle,* flew to meet the command module at the end of the *Apollo 11* mission. Seen from this viewpoint, Earth is illuminated from above.

Eclipses

Bodies orbiting the sun, including Earth and its moon, cast long shadows into space. An **eclipse** occurs when one celestial body passes through the shadow of another. Shadows cast by Earth and the moon have two parts. In the inner, cone-shaped part of the shadow, the *umbra*, sunlight is completely blocked. In the outer part of the shadow, the *penumbra*, sunlight is only partially blocked, as shown in **Figure 3.**

Figure 3 ▶ During a solar eclipse, the shadow of the moon falls on Earth. The distance between Earth and the moon in this diagram is not to scale.

eclipse an event in which the shadow of one celestial body falls on another

solar eclipse the passing of the moon between Earth and the sun; during a solar eclipse, the shadow of the moon falls on Earth

Solar Eclipses

When the moon is directly between the sun and part of Earth, the shadow of the moon falls on Earth and causes a **solar eclipse.** During a *total solar eclipse*, the sun's light is completely blocked by the moon. The umbra falls on the area of Earth that lies directly in line with the moon and the sun. Outside the umbra, but within the penumbra, people see a *partial solar eclipse*. The penumbra falls on the area that immediately surrounds the umbra.

The umbra of the moon is too small to make a large shadow on Earth's surface. The part of the umbra that hits Earth during an eclipse, as shown in **Figure 4,** is never more than a few hundred kilometers across. So, a total eclipse of the sun covers only a small part of Earth and is seen only by people in particular parts of Earth along a narrow path. A total solar eclipse also never lasts more than about seven minutes at any one location. A total eclipse will not be visible in the United States until 2017, even though there is a total eclipse somewhere on Earth about every 18 months.

Figure 4 ▶ The dark area (right) is the shadow of the moon cast on cloudtops over Europe during a total solar eclipse in 1999. The photo was taken from the orbiting space station *Mir*. The composite (left) shows a total solar eclipse over several hours.

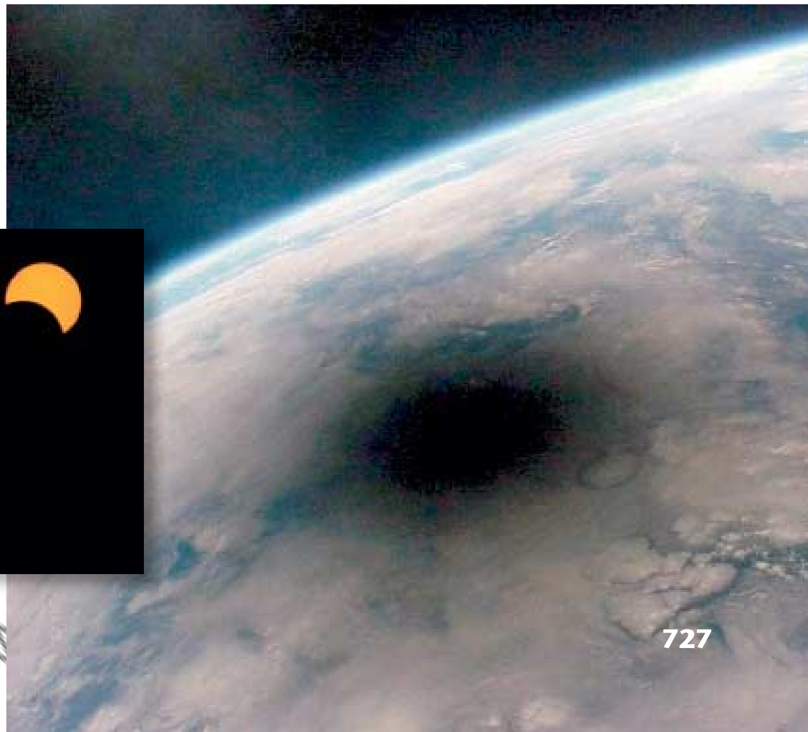


Figure 5 ▶ The diamond-ring effect produced by a solar eclipse can be stunning for observers on the part of Earth that falls under the moon's shadow.

Effects of Solar Eclipses

During a total solar eclipse, people on the ground are in the moon's umbra. In the areas on Earth's surface under the umbra, the sky becomes as dark as it does at twilight. During this period of darkness, the sunlight that is not eclipsed by the moon shows the normally invisible outer layers of the sun's atmosphere. The last bits of normal sunlight before darkness often glisten like the diamond on a ring and cause what is known as the *diamond-ring effect*. The diamond-ring effect is shown in **Figure 5.** Therefore, many people think that total solar eclipses are very beautiful.

If the moon is at or near apogee when it comes directly between Earth and the sun, the moon's umbra does not reach Earth. If the umbra fails to reach Earth, a ring-shaped eclipse occurs. This type of eclipse is called an *annular eclipse,* because *annulus* is the Latin word for "ring." During an annular eclipse, the sun is never completely blocked out. Instead, a thin ring of sunlight is visible around the outer edge of the moon. The brightness of this thin ring of ordinary sunlight prevents observers from seeing the outer layers of the sun's atmosphere that are visible during a total solar eclipse.

Reading Check **What is one difference between a total solar eclipse and an annular eclipse? (See the Appendix for answers to Reading Checks.)**

QuickLAB 15 min

Eclipses

Procedure

1. Make two balls from **modeling clay,** one about 4 cm in diameter and one about 1 cm in diameter.
2. Using a **metric ruler,** position the balls about 15 cm apart on a **sheet of paper,** as shown in the photo at right.
3. Turn off any nearby lights. Place a **penlight** approximately 15 cm in front of and almost level with the larger ball. Shine the light on the larger ball. Sketch your model, and note the effect of the beam of light.
4. Repeat step 3, but reverse the positions of the two balls. You may need to raise the smaller ball slightly to center its shadow on the larger ball. Sketch your model, and again note the effect of the light beam.

Analysis

1. Which planetary bodies do the larger clay ball, the smaller clay ball, and the penlight represent?
2. As viewed from Earth, what event did your model in step 3 represent? As viewed from the moon, what would your model represent?
3. As viewed from Earth, what event did your model in step 4 represent? As viewed from the moon, what would your model represent?
4. In what ways could you modify this activity to more closely model how eclipses occur?

Figure 6 ▶ During a lunar eclipse, the shadow of Earth falls on the moon. The distance between Earth and the moon in this diagram is not to scale.

Lunar Eclipses

A **lunar eclipse** occurs when Earth is positioned between the moon and the sun and when Earth's shadow crosses the lighted half of the moon. For a total lunar eclipse to occur, the entire moon must pass into Earth's umbra, as shown in **Figure 6.** When only part of the moon passes into Earth's umbra, a *partial lunar eclipse* occurs. The remainder of the moon passes through Earth's penumbra. When the entire moon passes through Earth's penumbra, a *penumbral eclipse* occurs. During a penumbral eclipse, the moon darkens so little that the eclipse is barely noticeable.

A lunar eclipse may last for more than an hour. Even during a total lunar eclipse, sunlight is bent around Earth through our atmosphere. Mainly red light reaches the moon, so the totally eclipsed moon appears to have a reddish color, as shown in the middle portion of the composite image in **Figure 7.**

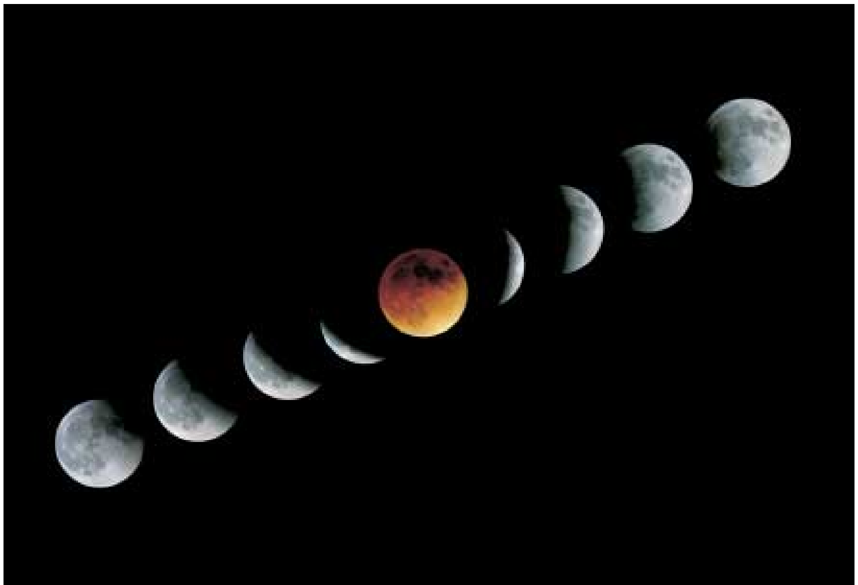
lunar eclipse the passing of the moon through Earth's shadow at full moon

Frequency of Solar and Lunar Eclipses

As many as seven eclipses may occur during a calendar year. Four may be lunar, and three may be solar or vice versa. However, total eclipses of the sun and the moon occur infrequently. Solar and lunar eclipses do not occur during every lunar orbit. This is because the orbit of the moon is not in the same plane as the orbit of Earth around the sun. The moon crosses the plane of Earth's orbit only twice in each revolution around Earth. A solar eclipse will occur only if this crossing occurs when the moon is between Earth and the sun. If this crossing occurs when Earth is between the moon and the sun, a lunar eclipse will occur.

Lunar eclipses are visible everywhere on the dark side of Earth. A total solar eclipse, however, can be seen only by observers in the small path of the moon's shadow as it moves across Earth's lighted surface. A partial solar eclipse can be seen for thousands of kilometers on either side of the path of the umbra.

Figure 7 ▶ This composite image shows a total lunar eclipse as seen from Earth over several hours.



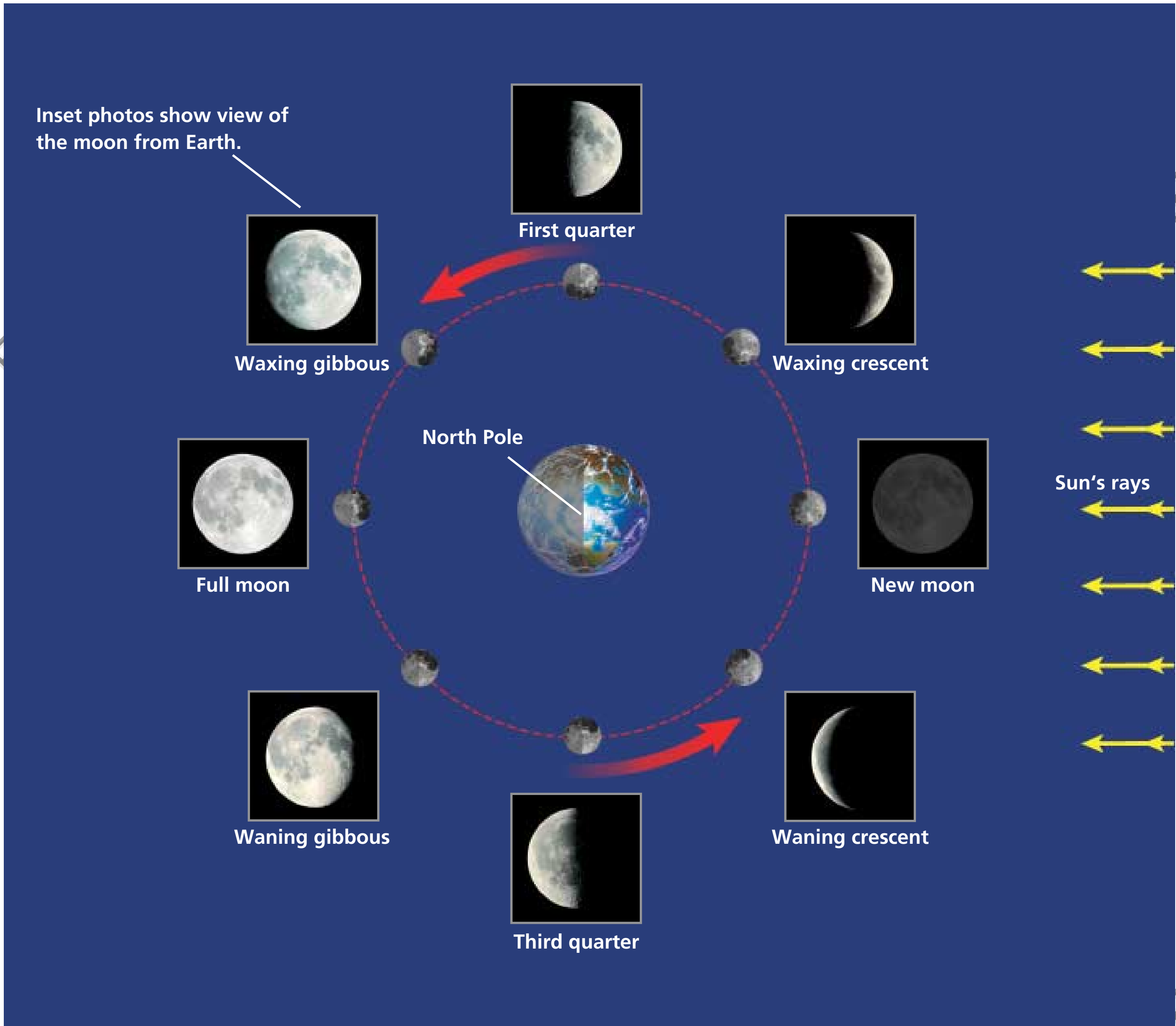
Phases of the Moon

On some nights, the moon shines brightly enough for you to read a book by its light. But moonlight is not produced by the moon. The moon merely reflects light from the sun. Because the moon is spherical, half of it is always lit by sunlight. As the moon revolves around Earth, however, different amounts of the near side of the moon, which faces Earth, are lighted. Therefore, the apparent shape of the visible part of the moon varies. These varying shapes, lighted by reflected sunlight, are called **phases** of the moon and are shown in **Figure 8.**

phase in astronomy, the change in the illuminated area of one celestial body as seen from another celestial body; phases of the moon are caused by the changing positions of Earth, the sun, and the moon

When the moon is directly between the sun and Earth, the sun's rays strike only the far side of the moon. As a result, the entire near side of the moon is dark. When the near side is dark, the moon is said to be in the *new-moon* phase. During this phase, no lighted area of the moon is visible from Earth.

Figure 8 ▶ Phases of the Moon



Waxing Phases of the Moon

As the moon continues to move in its orbit around Earth, part of the near side becomes illuminated. When the size of the lighted part of the moon is increasing, the moon is said to be *waxing*. When a sliver of the moon's near side is illuminated, the moon enters its *waxing-crescent* phase.

When the moon has moved through one-quarter of its orbit after the new moon phase, the moon appears to be a semicircle. Half of the near side of the moon is lighted. When a waxing moon becomes a semicircle, the moon enters its *first-quarter* phase. When the lighted part of the moon's near side is larger than a semicircle and still increasing in size, the moon is in its *waxing-gibbous* phase. The moon continues to wax until it appears as a full circle. At *full moon*, Earth is between the sun and the moon. Consequently, the entire near side of the moon is illuminated by the light of the sun.

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Topic: Lunar Cycle
SciLinks code: HQ60887

Waning Phases of the Moon

After the full moon phase, when the lighted part of the near side of the moon appears to decrease in size, the moon is *waning*. When it is waning but the lighted part is still larger than a semicircle, the moon is in the *waning-gibbous* phase. When the lighted part of the near side becomes a semicircle, the moon enters the *last-quarter* phase. When only a sliver of the near side is visible, the moon enters the *waning-crescent* phase. After the waning-crescent phase, the moon again moves between Earth and the sun. The moon once more becomes a new moon, and the cycle of phases begins again.

Before and after a new moon, only a small part of the moon shines brightly. However, the rest of the moon is not completely dark. It shines dimly from sunlight that reflects first off Earth's clouds and oceans and then reflects off the moon. Sunlight that is reflected off Earth is called *earthshine*. The darker part of the moon shown in **Figure 9** is lit by earthshine.

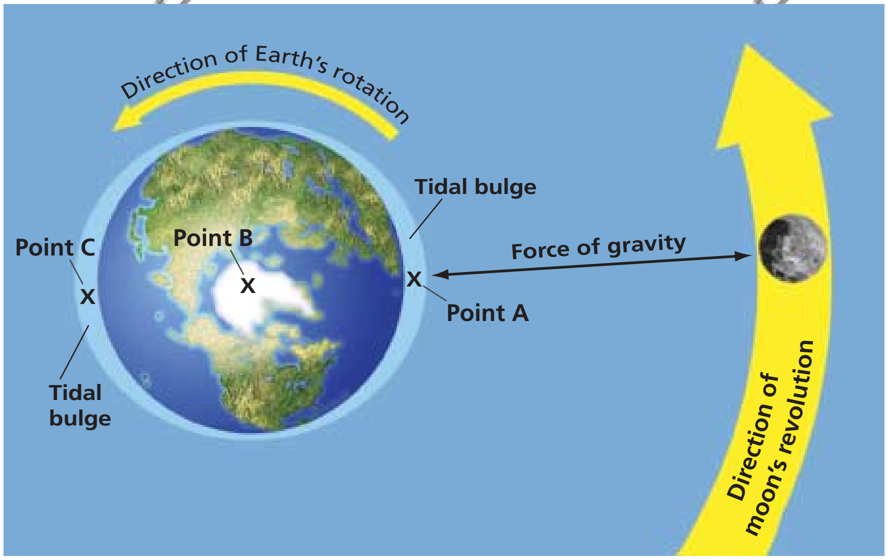
Figure 9 ▶ The darker portion of this crescent moon is not completely dark because some sunlight is reflected from Earth, to the moon, and back to Earth.

Time from New Moon to New Moon

Although the moon revolves around Earth in 27.3 days, a longer period of time is needed for the moon to go through a complete cycle of phases. The period from one new moon to the next one is 29.5 days. This difference of 2.2 days is due to the orbiting of the Earth-moon system around the sun. In the 27.3 days in which the moon orbits Earth, the two bodies move slightly farther along their orbit around the sun. Therefore, the moon must go a little farther to be directly between Earth and the sun. About 2.2 days are needed for the moon to travel this extra distance. The position directly between Earth and the sun is the position of the moon in each new moon phase.

Reading Check **Describe two phases of the waning moon. (See the Appendix for answers to Reading Checks.)**

Figure 10 ▶ The moon's pull on Earth is greatest at point A, on Earth's near side, and weakest at point C, on Earth's far side. Point B represents Earth's center of mass. Earth's rotation causes two low tides and two high tides each day on most shorelines.



Tides on Earth

Bulges in Earth's oceans, called *tidal bulges,* form because the moon's gravitational pull on Earth decreases with distance from the moon. As a result, the ocean on Earth's near side is pulled toward the moon with the greatest force. The solid Earth, which acts as though all of its mass were at Earth's center, experiences a lesser force. The ocean on Earth's far side is subject to less force than the solid Earth is. As shown in **Figure 10,** these differences cause Earth's tidal bulges. Because Earth rotates, tides occur in a regular rhythm at any given point on Earth's surface each day. The sun also causes tides, but they are smaller because the sun is so much farther from Earth than the moon is.

Section 2 Review

1. **Explain** why the moon rises and sets about 50 minutes later each successive night.
2. **Describe** the conditions that cause a total solar eclipse to occur.
3. **Explain** why a lunar eclipse does not occur every time the moon revolves around Earth in its monthly orbit.
4. **Summarize** how a solar eclipse differs from a lunar eclipse.
5. **Describe** the relative locations of the sun, Earth, and the moon during a new moon phase.
6. **Describe** how the appearance of the moon changes when it is waxing.
7. **Explain** why the moon repeats phases every 29.5 days even though it orbits Earth every 27.3 days.
8. **Explain** how the moon causes tidal bulges on Earth.

CRITICAL THINKING

9. **Analyzing Ideas** Explain why observers on Earth always see the same side of the moon.
10. **Making Comparisons** Explain why more people see each total lunar eclipse than each total solar eclipse.
11. **Analyzing Relationships** The sun's gravity also affects tides on Earth. Why does the moon have a larger effect on tides than the sun does?

CONCEPT MAPPING

12. Use the following terms to create a concept map: *Earth, moon, sun, eclipse, solar eclipse, lunar eclipse, umbra,* and *penumbra.*

Section 3 Satellites of Other Planets

Until the 1600s, astronomers thought that Earth was the only planet that had a moon. In 1610, Galileo discovered four moons orbiting Jupiter. He also observed what later were identified as the rings of Saturn. Since the time of Galileo, astronomers have discovered that all of the planets in our solar system except Mercury and Venus have moons. In addition, the gas giants Saturn, Jupiter, Uranus, and Neptune all have rings.

OBJECTIVES

- **Compare** the characteristics of the two moons of Mars.
- **Describe** how volcanoes were discovered on Io.
- **Name** one distinguishing characteristic of each of the Galilean moons.
- **Compare** the characteristics of the rings of Saturn with the rings of the other outer planets.

KEY TERM

Galilean moon

Moons of Mars

Mars has two tiny moons, named Phobos and Deimos. They revolve around Mars relatively quickly. Phobos and Deimos are irregularly shaped chunks of rock and are thought to be captured asteroids. Phobos is 27 km across at its longest, and Deimos is about 15 km across at its longest.

The surfaces of Phobos and Deimos are dark like maria on Earth's moon. Both moons have many craters. The large number of craters shows that the moons have been hit by many meteorites and asteroids, and suggests that the moons are fairly old.

Moons of Jupiter

Galileo observed four large moons revolving around Jupiter. Since that discovery was made, scientists have observed dozens of smaller moons around Jupiter. Smaller moons continue to be discovered today. Most of Jupiter's moons have diameters of less than 200 km, but of the largest four, known as the **Galilean moons,** three are bigger than Earth's moon. Until spacecraft flew near the moons, scientists knew little about them. Now, scientists have identified many unique characteristics of the Galilean moons. One of the four Galilean moons is shown in **Figure 1.**

Galilean moon any one of the four largest satellites of Jupiter—Io, Europa, Ganymede, and Callisto—that were discovered by Galileo in 1610

Figure 1 ▶ The stormy surface of Jupiter is visible in the background. In the foreground is Io, which orbits Jupiter once every 42 hours.

Figure 2 ▶ In this image taken by the *Galileo* spacecraft you can see a volcanic eruption on the left side of Io against the background of space.

Io

Io is the innermost of Jupiter's four Galilean moons. An engineer examining images from the *Voyager* spacecraft discovered volcanoes on Io. Io is the first extraterrestrial body on which active volcanoes have been seen. Since the discovery of Io's volcanoes, scientists realize that volcanism is more widespread in the solar system than they had thought. Volcanoes on Io eject thousands of metric tons of material each second. The lava that erupts on Io is much hotter than the lava that erupts on Earth. The temperature of the lava on Io is higher because the lava has more magnesium and iron than lava on Earth does. Plumes of volcanic material on Io reach heights of hundreds of kilometers, as shown in **Figure 2.** Because parts of Io's surface are yellow-red, scientists think that the volcanic material is mostly sulfur and sulfur dioxide.

Io moves inward and outward in its orbit around Jupiter because of the gravitational pull of the other moons of Jupiter. These *tidal forces* are caused by the difference between the force on one side of Io and that on the other side. These forces are similar to tides on Earth caused by the pull of the moon. As Io is pulled back and forth, its surface also moves in and out. Calculations show that tidal forces make Io's surface move in and out by 100 m. Heat from the friction caused by this surface flexing results in the melting of the interior of Io and leads to volcanism. Data from the *Galileo* spacecraft show that Io has a giant iron core and may possess a magnetic field. Much of what we know about Jupiter's moons came from information gathered by the *Galileo* spacecraft, which orbited Jupiter from 1995 to 2003.

Connection to GEOLOGY

Extraterrestrial Volcanism

Volcanoes on Earth can be compared to volcanoes that exist elsewhere in the universe. Recent discoveries have revealed that volcanism was very common in our solar system's past. Mars and Venus each have giant volcanoes that are now extinct. Some of these volcanoes are much bigger than the largest volcanoes on Earth. Mars's Olympus Mons is 600 km across and 25 km tall. The largest volcano on Earth, Hawaii's Mauna Loa, is only 17 km tall. Radar images show lava flows on Venus that extend for hundreds of kilometers. Venus and Mars also have many smaller volcanic landforms.

It was a surprise when the *Voyager I* spacecraft, flying by in 1979, revealed interesting and complex structures on the Galilean moons. Because of its small size, Io was expected to be a geologically dead world, like Earth's moon. Some long-exposure images were taken of Io to show the stars behind it and to help track the spacecraft's position. Linda Morabito, an engineer working at the California Institute of Technology's Jet Propulsion Laboratory, examined the images and noticed something extending over Io's edge. It could not be a cloud, because Io had no atmosphere. A volcano was the only possibility. Since that time, scientists have realized that Io is the most volcanically active place in the solar system.

The only other place in the solar system where active volcanism is known is on Neptune's moon Triton. The *Voyager 2* spacecraft observed dark streaks on Triton's surface that show where nitrogen that erupted from below Triton's surface was carried downwind.

The black plumes at the bottom left of the photo are from an erupting volcano on Io.

Europa

Europa is the second closest Galilean moon to Jupiter. Europa is about the size of Earth's moon, but Europa is much less dense than Earth's moon. Astronomers think that Europa has a rock core that is covered with a crust of ice that is about 100 km thick. Images of Europa, such as the one shown in **Figure 3,** show cracks in this enormous ice sheet.

Scientists have concluded from observations made from spacecraft that an ocean of liquid water may exist under this blanket of ice. If liquid water exists, simple forms of life could also exist there. Astronomers have no evidence of life on Europa, but many think Europa would be a good place to investigate the possibility of extraterrestrial life.

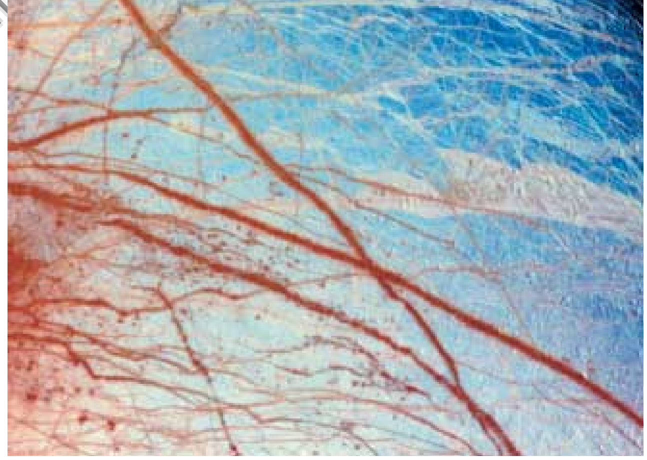


Figure 3 ▶ This false-color image of Europa shows immense cracks across its ice sheets.

Ganymede

Ganymede is the third Galilean moon from Jupiter. Ganymede is also the largest moon in the solar system, even larger than the planet Mercury. However, Ganymede has a relatively small mass because it is probably composed mostly of ice mixed with rock.

Images of Ganymede, such as **Figure 4,** show dark, crater-filled areas. Other light areas show marks that are thought to be long ridges and valleys. The Galileo spacecraft provided evidence to support the existence of a magnetic field around Ganymede. Ganymede and Io are the only Galilean moons that have strong magnetic fields. Both moons' magnetic fields are completely surrounded by Jupiter's much more powerful magnetic field.

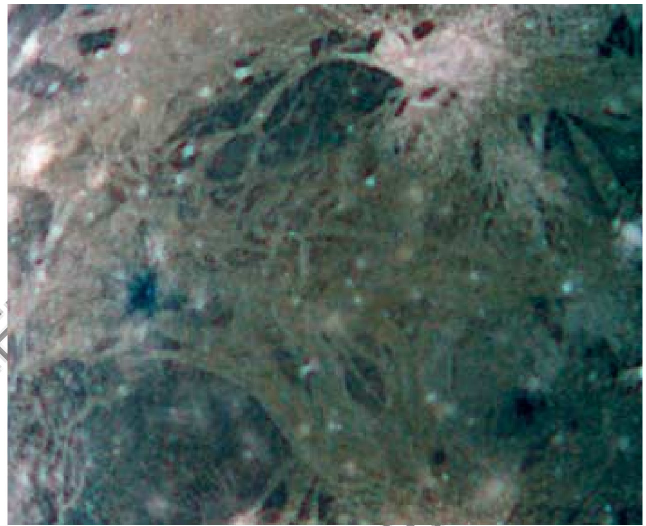


Figure 4 ▶ Much of Ganymede's surface is covered with ridges and valleys.

Callisto

Of the four Galilean moons, Callisto is the farthest from Jupiter. Callisto is similar to Ganymede in size, density, and composition. However, Callisto has a much rougher surface than Ganymede does. In fact, Callisto may be one of the most densely cratered moons in our solar system.

Like craters on Earth's moon and other bodies in our solar system, craters on Callisto are the result of collisions that occurred early in the history of the solar system. **Figure 5** shows a giant impact basin that is 600 km across and a set of concentric rings that extend about 1,500 km outward in all directions from the crater.

Reading Check **Name one feature of each of the Galilean moons. (See the Appendix for answers to Reading Checks.)**

Figure 5 ▶ "Ripples" of ice and rock radiate out from this impact crater, called *Valhalla*, on Callisto.

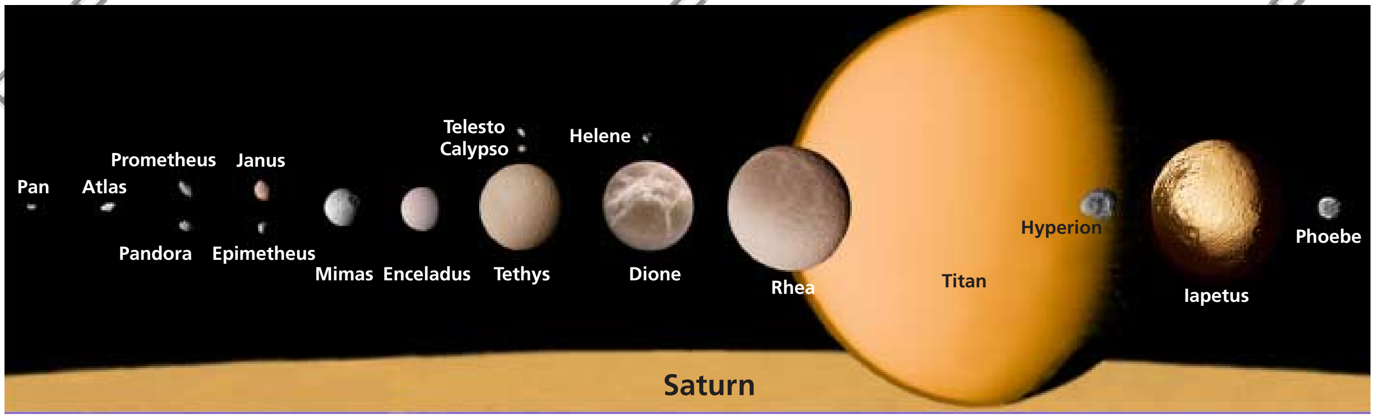


Figure 6 ▶ This composite image shows Saturn and many of Saturn's largest moons. The distances of the moons from Saturn and from each other are not to scale.

Moons of Saturn

Saturn has at least 30 moons. Most of them are small, icy bodies that have many craters. However, five of Saturn's moons are fairly large. These five moons and many of Saturn's other moons are shown in **Figure 6.**

Graphic Organizer **Comparison Table**

Create the Graphic Organizer entitled "Comparison Table" described in the Skills Handbook section of the Appendix. Label the columns with "Moons of Mars," Moons of Jupiter," "Moons of Saturn, and "Moons of Uranus and Neptune." Fill in the table with details about each moon as you read this section.

Titan

Saturn's largest moon, called Titan, has a diameter of more than 5,000 km. Only Jupiter's moon Ganymede is larger. Unlike any of the other moons in our solar system, Titan has a thick atmosphere that is composed mainly of nitrogen. Titan's atmosphere is so thick that hydrocarbon smog conceals the surface. Observations made by using infrared sensors have indicated that Titan's surface may contain lakes or oceans of liquid methane.

In 2005, the *Huygens* (HIE guhnz) probe, which is part of the Cassini mission, gathered data about Titan's atmosphere. Titan's atmospheric composition should give scientists clues about how Titan and its atmosphere formed. Data on Titan's surface may give clues about the moon's interior.

Saturn's Other Moons

Saturn's icy moons resemble Jupiter's icy Galilean moons. Saturn's other smaller moons have irregular shapes. Scientists think that many of the smallest moons, such as Janus, which is shown in **Figure 7,** were captured by Saturn's gravitational pull.

Figure 7 ▶ This image of Janus was taken by the *Voyager 1* spacecraft as the moon orbited near Saturn's rings.

Moons of Uranus and Neptune

Uranus's four largest moons, Oberon, Titania, Umbriel, and Ariel, were known by the mid-1800s. A fifth, Miranda, was discovered in 1948 and is shown in **Figure 8.** Other much smaller moons have been discovered recently by using spacecraft and orbiting observatories such as the *Hubble Space Telescope*. Astronomers know that Uranus has at least two dozen small moons.

Neptune has at least eight moons. Triton, an icy moon, is unusual because it revolves around Neptune in a backward, or *retrograde,* orbit. Some astronomers think that Triton has an unusual orbit because the moon was probably captured by the gravity of Neptune after forming elsewhere in the solar system and then coming too close to the planet. Triton's diameter is 2,705 km, and the moon has a thin atmosphere.

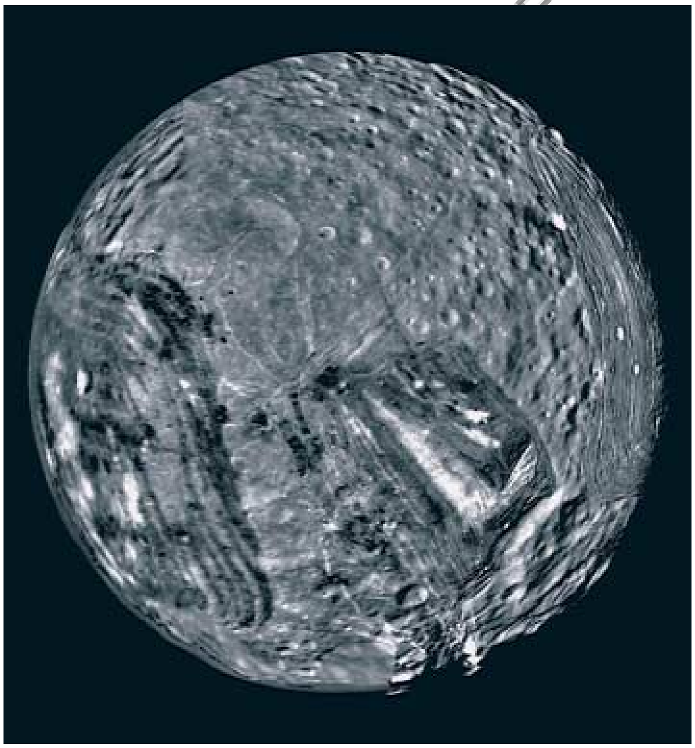


Figure 8 ▶ Uranus's moon called Miranda shows intriguing evidence of past geologic activity.

Pluto's Moon

Pluto is different from the other outer planets. Pluto's orbit is more elliptical and at a different angle than the other planets' orbits. Some scientists think that Pluto should not be considered a planet because several objects that are similar to Pluto in size and composition exist near Pluto's orbit.

Unlike the relationships between other moons and planets in the solar system, Pluto's moon Charon (KER uhn) is almost half the size of Pluto. Because Pluto and Charon are similar in size, some scientists consider them to be a double-planet system. Charon completes one orbit around Pluto in 6.4 days, the same length of time as a day on Pluto. Because of these equal lengths, Charon stays in the same place in Pluto's sky. In the same way that one side of Earth's moon faces toward Earth, one side of Pluto always faces toward Charon.

Reading Check **Identify two ways Charon is different from other moons. (See the Appendix for answers to Reading Checks.)**

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Topic: Moons of Other Planets

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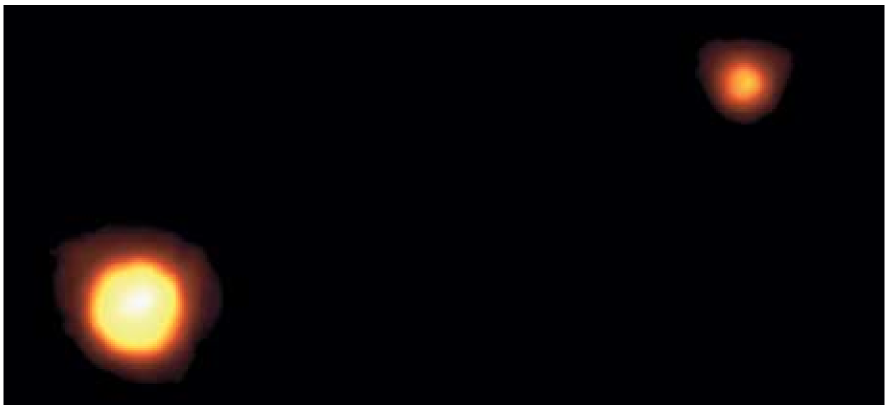

Figure 9 ▶ Charon has a diameter almost half as large as Pluto's. Pluto was discovered in 1930, and Charon was discovered in 1978.

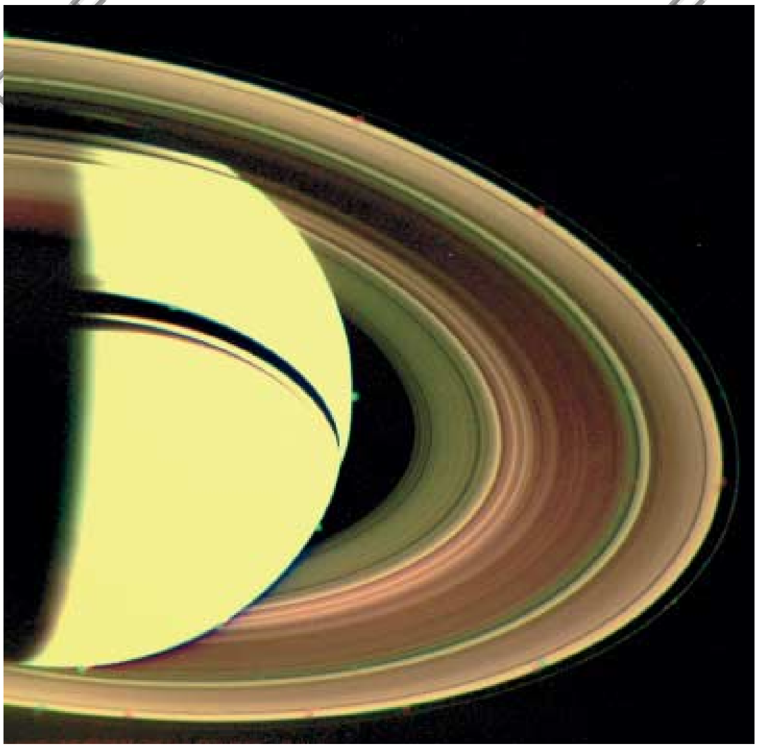

Figure 10 ▶ Saturn has the most extensive system of rings in the solar system. The angle at which its rings are visible changes as Saturn orbits the sun.

Rings of the Gas Giants

Saturn's spectacular set of rings, shown in **Figure 10,** was discovered more than 300 years ago. Each of the rings circling Saturn is divided into hundreds of small ringlets. The ringlets are composed of billions of pieces of rock and ice. These pieces range in size from particles the size of dust to chunks the size of a house. Each piece follows its own orbit around Saturn. The ring system of Saturn is very thin.

Originally, astronomers thought that the rings formed from material that was unable to clump together to form moons while Saturn was forming. However, evidence indicates that the rings are much younger than originally thought. Now, most scientists think that the rings are the remains of a large cometlike body that entered Saturn's system and was ripped apart by tidal forces. Particles from the rings continue to spiral into Saturn, but the rings are replenished by particles given off by Saturn's moons.

The other gas giants have rings as well. These rings are relatively narrow. Jupiter's were not discovered until the *Voyager 1* spacecraft flew by Jupiter in 1979. Jupiter has a single, thin ring made of microscopic particles that may have been given off by Io or one of Jupiter's other moons. The particles may also be debris from collisions of comets or meteorites with Jupiter's moons. Uranus also has a dozen thin rings. Neptune's relatively small number of rings are clumpy rather than thin and uniform.

Section 3 Review

1. **Compare** the characteristics of Phobos and Deimos.
2. **List** the four moons of Jupiter that were discovered by Galileo, and identify one distinguishing characteristic of each.
3. **Describe** how volcanoes were discovered on Io.
4. **Explain** why Io remains volcanically active.
5. **Describe** how the smaller moons of Uranus were discovered.
6. **Explain** why Triton has an unusual orbit.
7. **Compare** the characteristics of Saturn's rings with the rings of the other outer planets.

CRITICAL THINKING

8. **Analyzing Relationships** Explain why scientists think that Ganymede's interior includes ice.
9. **Inferring Relationships** Compare and contrast the way in which moons and ring systems form.
10. **Making Comparisons** Explain why Triton retains an atmosphere while Phobos does not.

CONCEPT MAPPING

11. Use the following terms to create a concept map: *moon, ring, Mars, Uranus, Jupiter, Saturn, Phobos, Deimos, Pluto, Galilean moon, natural satellite, Charon, Titania,* and *Titan.*

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Section 4 Asteroids, Comets, and Meteoroids

In addition to the sun, the planets, and the planets' moons, our solar system includes millions of smaller bodies. Some of these small bodies are tiny bits of dust or ice that orbit the sun. Other bodies are as big as small moons. Astronomers theorize that these smaller bodies are leftover debris from the formation of the solar system.

OBJECTIVES

- **Describe** the physical characteristics of asteroids and comets.
- **Describe** where the Kuiper belt is located.
- **Compare** meteoroids, meteorites, and meteors.
- **Explain** the relationship between the Oort cloud and comets.

KEY TERMS

asteroid
comet
Oort cloud
Kuiper belt
meteoroid
meteor

Asteroids

The largest of the smaller bodies in the solar system are called asteroids. **Asteroids** are fragments of rock that orbit the sun. Astronomers have discovered more than 50,000 asteroids. Millions of asteroids may exist in the solar system. The orbits of asteroids, like those of the planets, are ellipses. The largest known asteroid, Ceres, has a diameter of about 1,000 km. Two other asteroids are shown in **Figure 1.** The large size of some asteroids leads some scientists to refer to them as "minor planets."

Most asteroids are located in a region between the orbits of Mars and Jupiter known as the *asteroid belt*. This main belt extends from about 299 million to about 598 million kilometers from the sun. However, not all asteroids are located in the main asteroid belt. The closest asteroids to the sun are inside the orbit of Mars, about 224 million kilometers from the sun. The *Trojan asteroids* are concentrated in groups just ahead of and just behind Jupiter as it orbits the sun. In fact, the Trojan asteroids almost share Jupiter's orbit. These asteroids are name for the Trojan and Greek warriors of the famous Trojan War of Greek mythology. Asteroids also exist beyond Jupiter's orbit.

asteroid a small, rocky object that orbits the sun; most asteroids are located in a band between the orbits of Mars and Jupiter

Figure 1 ▶ This image of the asteroids Ida (left) and Dactyl (right) were taken by the spacecraft *Galileo* as it passed through the asteroid belt on its way to Jupiter. Ida is 56 km long, and Dactyl is 1.5 km across.

Composition of Asteroids

The composition of asteroids is similar to that of the inner planets. Asteroids are classified according to their composition into three main categories. The most common of the three types of asteroids is made of mostly silicate minerals. These asteroids look like Earth rocks. The second type of asteroid is composed of mostly iron and nickel. These asteroids have a shiny, metallic appearance, especially on fresh surfaces. The third, and rarest, type of asteroid is made mostly of carbon materials, which give this type of asteroid a dark color.

Many astronomers think that asteroids in the asteroid belt are made of material that was not able to form a planet because of the strong gravitational force of Jupiter. Scientists estimate that the total mass of all asteroids—including the largest, Ceres—is less than the mass of Earth's moon.

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Near-Earth Asteroids

More than a thousand asteroids have orbits that sometimes bring them very close to Earth. These asteroids have wide, elliptical orbits that bring them near Earth's orbit. Thus they are called *near-Earth asteroids*. Near-Earth asteroids make up only a small percentage of the total number of asteroids in the solar system.

Interest in near-Earth asteroids has increased in recent years with the realization that these asteroids could inflict great damage on Earth if they were to strike the planet. Meteor Crater, in Arizona, which is shown in **Figure 2**, formed when a small asteroid that had a diameter of less than 50 m struck Earth about 40,000 years ago. Several recently established asteroid detection programs have begun to track all asteroids whose orbits may approach Earth. By identifying and monitoring these asteroids, scientists hope to predict and possibly avoid future collisions.

Reading Check **What are the three types of asteroids? (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ Barringer Meteorite Crater, also known simply as Meteor Crater, in Arizona, has a diameter of more than 1 km. Dozens of such craters have resulted from past impacts on Earth, but most craters have eroded or have been covered by sediment.

Figure 3 ▶ A comet, such as Comet Hale-Bopp, consists of a nucleus, a coma, and two tails. The blue streak is the *ion tail,* and the white streak is the *dust tail.*

Comets

Every few years, an object that looks like a star that has a tail is visible in the evening sky. This object is a comet. **Comets** are small bodies of ice, rock, and cosmic dust that follow highly elliptical orbits around the sun. The most famous is Halley's Comet, which passes by Earth every 76 years. It last passed Earth in 1986 and will return in 2061. Every 5 to 10 years, another very bright comet will be visible from Earth. Comet Hale-Bopp, shown in **Figure 3,** was particularly bright and spectacular as it passed by Earth in 1997.

comet a small body of rock, ice, and cosmic dust that follows an elliptical orbit around the sun and that gives off gas and dust in the form of a tail as it passes close to the sun

Composition of Comets

A comet has several parts. The core, or nucleus, of a comet is made of rock, metals, and ice. Cores of comets are commonly between 1 km and 100 km in diameter. A spherical cloud of gas and dust, called the *coma,* surrounds the nucleus. The coma can extend as far as 1 million kilometers from the nucleus. A comet's bright appearance largely results from sunlight reflected by the comet's coma. The nucleus and the coma form the head of the comet. In 2004, material was collected by the spacecraft *Stardust* from the coma of a comet named Wild 2. The spacecraft flew to within 240 km of the comet's nucleus and collected the first detailed images of a comet's nucleus.

The most spectacular parts of a comet are its tails. Tails form when sunlight causes the comet's ice to change to gas. The gas, or ion, tail of a comet streams from the comet's head. The solar wind—electrically charged particles expanding away from the sun—pushes the gas away from the comet's head. Thus, regardless of the direction the comet travels, its ion tail points away from the sun. The comet's second tail is made of dust and curves backward along the comet's orbit. Some comets have tails that are more than 80 million kilometers long.

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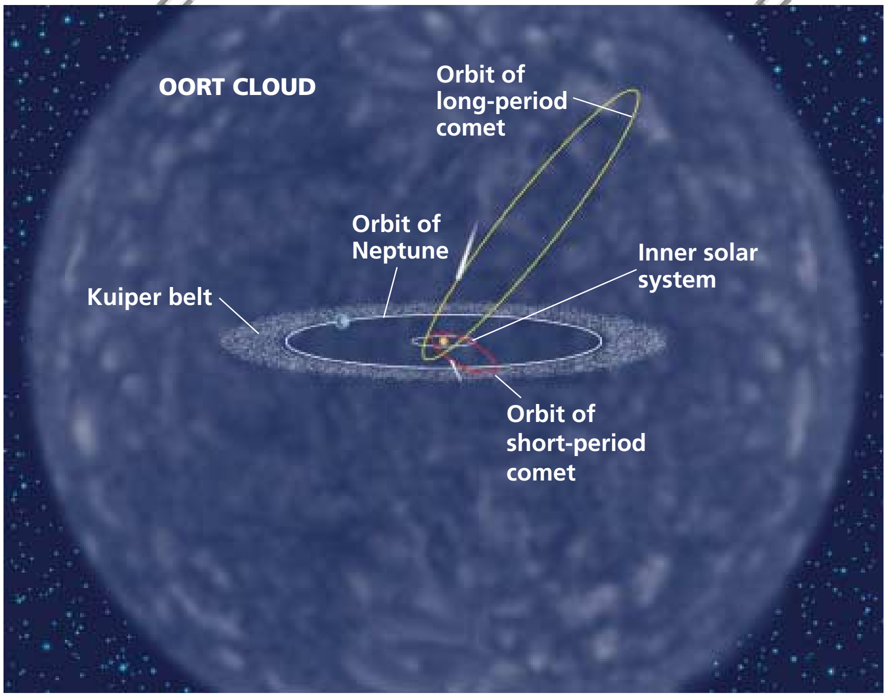
Figure 4 ▶ Most comets come from the Oort cloud, a region in the outer solar system that is beyond the orbit of Pluto.



Oort cloud a spherical region that surrounds the solar system, that extends from just beyond Pluto's orbit to almost halfway to the nearest star, and that contains billions of comets

Kuiper belt the flat region beyond Neptune's orbit that extends about twice as far as Neptune's orbit, that contains leftover planetesimals, and that is the source of many short-period comets

The Oort Cloud

Astronomers think that most comets originate in the Oort cloud, which is illustrated in **Figure 4.** The **Oort cloud** is a spherical cloud of dust and ice that lies far beyond Pluto's orbit and that contains the nuclei of billions of comets. The total mass of the Oort cloud is estimated to be between 10 and 40 Earth masses.

The Oort cloud surrounds the solar system and may reach as far as halfway to the nearest star. Scientists think that the matter in the Oort cloud was left over from the formation of the solar system. Studying this distant matter helps scientists understand the early history of the solar system.

Bodies within the Oort cloud circle the sun so slowly that they take a few million years to complete one orbit. But the gravity of a star that passes near the solar system may cause a comet to fall into a more elliptical orbit around the sun. The orbits of comets that pass by Jupiter may also be changed by Jupiter's gravitational force. If a comet takes more than 200 years to complete one orbit of the sun, the comet is called a *long-period comet*.

The Kuiper Belt

Recent advances in technology have allowed scientists to observe many small objects beyond the orbit of Neptune. Most of these objects, including some comets, are from a flat ring of objects, called the **Kuiper belt** (KIE puhr BELT), that is located just beyond Neptune's orbit. The Kuiper belt may contain thousands of *Kuiper belt objects* that have diameters larger than 100 km. Only two known objects are as large as half the size of Pluto. Pluto is located in the Kuiper belt during much of its orbit. Some astronomers do not consider Pluto to be a planet, and they consider Pluto and Charon to be two of many Kuiper belt objects.

Short-Period Comets

Comets called *short-period comets* take less than 200 years to complete one orbit around the sun. In recent years, astronomers have discovered that most short-period comets come from the Kuiper belt. Some of the comets that originate in the Kuiper belt have been forced outward into the Oort cloud by Jupiter's gravity. Many comets in the Kuiper belt are the result of collisions between larger Kuiper belt objects there. Halley's comet, which has a period of 76 years, is a short-period comet.

MATHPRACTICE

Matter From Space
Astronomers estimate that about 1 million kg of matter from meteoroids falls to Earth each day. Based on this estimate, how many kilograms of matter from meteoroids would fall on Earth in three weeks?

Meteoroids

In addition to relatively large asteroids and comets, very small bits of rock or metal move throughout the solar system. These small, rocky bodies are called **meteoroids.** Most meteoroids have a diameter of less than 1 mm. Scientists think that most meteoroids are pieces of matter that become detached from passing comets. Large meteoroids—more than 1 cm in diameter—are probably the result of collisions between asteroids.

meteoroid a relatively small, rocky body that travels through space

meteor a bright streak of light that results when a meteoroid burns up in Earth's atmosphere

Meteors

Meteoroids that travel through space on an orbit that takes them directly into Earth's path may enter Earth's atmosphere. When a meteoroid enters Earth's atmosphere, friction between the object and the air molecules heats the meteoroid's surface. As a result of this friction and heat, most meteoroids burn up in the atmosphere. As a meteoroid burns up in Earth's atmosphere, the meteoroid produces a bright streak of light called a **meteor.** Meteors are commonly called *shooting stars*. Meteoroids sometimes also vaporize very quickly in a brilliant flash of light called a *fireball*. Observers on Earth may hear a loud noise as a fireball disintegrates.

When a large number of small meteoroids enter Earth's atmosphere in a short period of time, a *meteor shower* occurs. During the most spectacular of these showers, several meteors are visible every minute. A composite photo of a meteor shower is shown in **Figure 5.** Meteor showers occur at the same time each year. This happens because Earth intersects the orbits of comets that have left behind a trail of dust. As these particles burn up in Earth's atmosphere, they appear as meteors streaking across the sky.

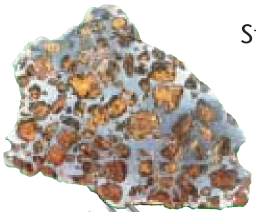
Reading Check **What is the difference between a meteor and a meteoroid? (See the Appendix for answers to Reading Checks.)**

Figure 5 ▶ The straight lines in this composite photo are meteors burning up as they move through Earth's atmosphere.

Figure 6 ▶ Types of Meteorites

Stony

Iron



Stony-iron

Meteorites

Millions of meteoroids enter Earth's atmosphere each day. A few of these meteoroids do not burn up entirely in the atmosphere because they are relatively large. These meteoroids fall to Earth's surface. A meteoroid or any part of a meteoroid that is left when a meteoroid hits Earth is called a *meteorite*. Most meteorites are small and have a mass of less than 1 kg. However, large meteorites occasionally strike Earth's surface with the force of a large bomb. These impacts leave large impact craters.

Meteorites can be classified into three basic types: stony, iron, and stony-iron. These three types of meteorites are shown in **Figure 6.** *Stony meteorites* are similar in composition to rocks on Earth. Some stony meteorites contain carbon-bearing compounds that are similar to the carbon compounds in living organisms. Although most meteorites are stony, *iron meteorites* are easier to find. Iron meteorites are easier to find because they have a distinctive metallic appearance. This distinctive appearance makes iron meteorites easy to distinguish from common Earth rocks. The third type of meteorites, called *stony-iron meteorites,* contain iron and stone. Stony-iron meteorites are rare.

Astronomers think that almost all meteorites come from collisions between asteroids. The oldest meteoroids may be 100 million years older than Earth and its moon. Therefore, meteorites may provide information about how the early solar system formed.

Some rare meteorites originated on the moon or Mars. Computer simulations have shown that meteorites that hit the moon or Mars can eject rocks that then fall to Earth. Many of these rare meteorites have been found in Antarctica. Finding meteorites in Antarctica is relatively easy because they stand out against the background of snow and ice.

Section 4 Review

1. **Identify** where the asteroid belt is located in the solar system.
2. **Describe** the physical characteristics of asteroids.
3. **List** the four main parts of a comet, and identify their physical characteristics.
4. **Compare** the ion and dust tails of a comet.
5. **Explain** the relationship between the Oort cloud and comets.
6. **Describe** the location of the Kuiper belt.
7. **Distinguish** between a meteor, a meteoroid, and a meteorite.

CRITICAL THINKING

8. **Analyzing Relationships** Explain why a comet's ion tail always points away from the sun.
9. **Making Comparisons** Explain one argument for considering Pluto to be a planet and one argument for considering Pluto to not be a planet.
10. **Making Comparisons** You find a meteorite on the ground. What kind of meteorite did you most likely find? Describe two steps of its journey from space.

CONCEPT MAPPING

11. Use the following terms to create a concept map: *comet, asteroid, Kuiper belt, Oort cloud, long-period comet, short-period comet,* and *meteoroid.*

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Chapter 28 Highlights

Sections

1 Earth's Moon

Key Terms

satellite, 719
moon, 719
mare, 720
crater, 720

Key Concepts

- The surface of the moon is covered by craters, rilles, and ridges.
- The structure of the moon's interior was determined by using seismographs.
- The moon may have formed when an object hit Earth more than 4 billion years ago. Lunar surface features have changed little since they formed 3 billion years ago.

2 Movements of the Moon

apogee, 725
perigee, 725
eclipse, 727
solar eclipse, 727
lunar eclipse, 729
phase, 730

- Eclipses occur when one planetary body passes through the shadow of another.
- The moon spins on its axis once during each orbit of Earth. As the moon orbits, the amount of the near side that is lighted increases and decreases, which causes phases.
- Tides on Earth are the result of the gravitational pull of the sun and the moon.

3 Satellites of Other Planets

Galilean moon, 733

- Phobos and Deimos, the two tiny moons of Mars, are much smaller than Earth's moon.
- The Galilean moons are the four largest satellites of Jupiter. Jupiter, Saturn, Uranus, and Neptune have rings.
- Uranus and Neptune each have several moons. Pluto has one moon named Charon.

4 Asteroids, Comets, and Meteoroids

asteroid, 739
comet, 741
Oort cloud, 742
Kuiper belt, 742
meteoroid, 743
meteor, 743

- Most asteroids are located in an asteroid belt that is located between the orbits of Mars and Jupiter.
- Comets come from the Oort cloud, which is beyond Pluto's orbit, and from the Kuiper belt, which is beyond Neptune's orbit.
- Meteoroids are small rocks in space that either burn up in Earth's atmosphere (as meteors) or stay intact to hit Earth (as meteorites).

Chapter 28 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *crater*
2. *mare*
3. *Galilean moon*

For each pair of terms, explain how the meanings of the terms differ.

4. *perigee* and *apogee*
5. *Oort cloud* and *Kuiper belt*
6. *solar eclipse* and *lunar eclipse*
7. *comet* and *asteroid*
8. *meteoroid* and *meteorite*

Understanding Key Concepts

9. Dark areas on the moon that are smooth and that reflect little light are called
   a. rilles. **c.** maria.
   b. rays. **d.** breccia.

10. What happened in the most recent stage in the development of the moon?
    a. The densest material sank to the core.
    b. The crust began to break.
    c. Earth's gravity captured the moon.
    d. The number of meteorites hitting the moon decreased.

11. During each orbit around Earth, the moon spins on its axis
    a. 1 time. **c.** about 27 times.
    b. about 29 times. **d.** 365 times.

12. In a lunar eclipse, the moon
    a. casts a shadow on Earth.
    b. is in Earth's shadow.
    c. is between Earth and the sun.
    d. blocks part of the sun from view.

13. When the size of the lighted part of the moon's near side is decreasing, the moon is
    a. full. **c.** annular.
    b. waxing. **d.** waning.

14. Compared with the other moons of Jupiter, the four Galilean moons are
    a. larger.
    b. farther from Jupiter.
    c. lighter.
    d. younger.

15. The main asteroid belt exists in a region between the orbits of
    a. Mercury and Venus. **c.** Venus and Earth.
    b. Earth and Mars. **d.** Mars and Jupiter.

16. Meteorites can provide information about
    a. the composition of the solar system before the planets formed.
    b. the size of Earth.
    c. the destiny of the solar system.
    d. the size of the universe.

Short Answer

17. Describe how maria formed on the moon.
18. Are craters on the moon caused by volcanism or by impacts with other bodies? Explain your answer.
19. Do total eclipses of the sun occur only at full moons? Explain your answer.
20. Are any moons in the solar system bigger than planets? Explain.
21. Which planets have rings?
22. Which two places in the solar system do comets come from?
23. What is the difference between natural and artificial satellites?

Critical Thinking

24. Analyzing Relationships If Earth had two moons that traveled on the same orbit and were the same distance from Earth, but formed a 90° angle with Earth, how would Earth's tides be different?

25. Making Inferences How would the craters on the moon be different today if the moon had developed a dense atmosphere that moved as wind and that contained water?

26. Determining Cause and Effect If meteorites had stopped hitting the moon before the outer surface of the moon cooled, how would the moon's surface be different than it is today?

27. Evaluating Information Suppose that the moon spun twice on its axis during each orbit around Earth. How would the study of the moon from Earth be easier than it is currently?

28. Applying Ideas The surfaces of some asteroids reflect only small amounts of light. Other asteroids reflect up to 40% of the light that falls on them. Of what kind of materials would each type of asteroid probably be composed?

Concept Mapping

29. Use the following terms to create a concept map: *moon, Earth, apogee, perigee, new moon, full moon, waxing, waning, solar eclipse, lunar eclipse, umbra, penumbra,* and *phase*.

Math Skills

30. Making Calculations There are 60 s in 1 min, 60 min in 1 h, 24 h in 1 day, and 365 1/4 days in a year. How many seconds are in a year?

31. Making Calculations The radius of Earth's moon is 1,738 km. The diameter of Neptune's moon Triton is 2,705 km. What percentage of Earth's moon's size is Triton?

Writing Skills

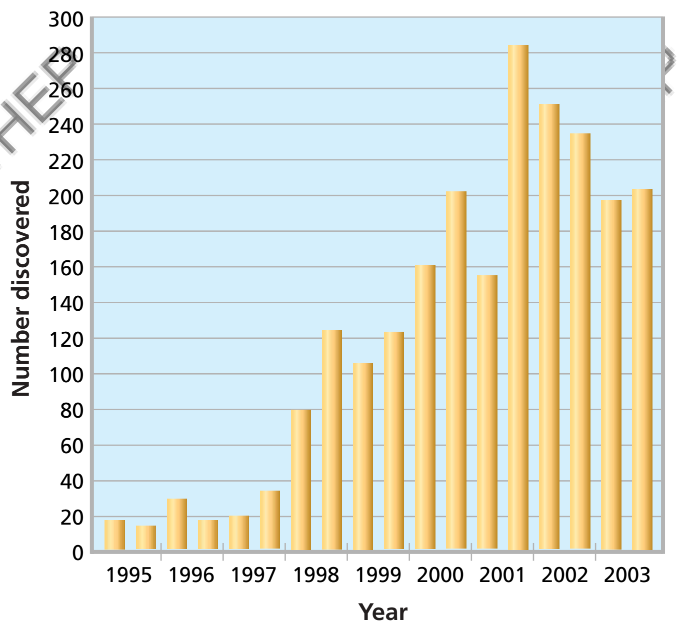
32. Creative Writing Imagine that you want to live on the moon. Describe how you would get your water and how you would acquire food and other supplies.

33. Communicating Ideas Summarize how the moon's gravity and the rotation of Earth cause tides.

Interpreting Graphics

The graph below shows the number of near-Earth asteroids discovered each year. Use the graph below to answer the questions that follow.

Near-Earth Asteroid Discoveries



34. Was the rate of discovery of near-Earth asteroids in 2003 higher or lower than the rate in 2000?

35. How many near-Earth asteroids were discovered in the half-year in which the most discoveries were made?

36. Which calendar year had the highest total number of near-Earth asteroid discoveries?

37. What is the total number of near-Earth asteroids discovered in the last three years shown on the graph?

Chapter 28 Standardized Test Prep

Understanding Concepts

Directions (1–4): **For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 Because of differences in surface gravity, how much does a person who weighs 360 newtons (360 N) on Earth weigh on the moon?

A. 36 N **C.** 180 N
B. 60 N **D.** 90 N

2 The point in the orbit of a satellite at which the satellite is farthest from Earth is the satellite's

F. apogee
G. perigee
H. barycenter
I. phase

3 Which of the following statements accurately describes each ring of Saturn?

A. It is divided into smaller ringlets, all of which orbit Saturn together.
B. It consists of a single ring composed of rock and ice pieces.
C. It is divided into smaller ringlets, each of which has an individual orbit.
D. It is part of a set of rings that are unlike those found anywhere else.

4 Which of the following statements describes why temperature variation on the moon is so large?

F. The moon has no atmosphere to provide insulation.
G. The atmosphere of the moon is made up of cold gases.
H. Gases are dense and close to the surface.
I. Dark, smooth rocks absorb the sun's heat.

Directions (5–7): **For *each* question, write a short response.**

5 Approximately how long does it take the moon to make one orbit around Earth?

6 What are the names of the four moons of Jupiter known as the Galilean moons?

7 When the moon is at its apogee, what part of its shadow cannot reach Earth during an eclipse?

Reading Skills

Directions (9–12): **Read the passage below. Then, answer the questions.**

Kuiper Belt Objects

To explain the source of short-period comets, or comets that have a relatively short orbit around the sun, the Dutch-American astronomer Gerard Kuiper proposed in 1949 that a belt of icy bodies must lie beyond the orbits of Pluto and Neptune. Kuiper argued that comets were icy planetesimals that formed from the condensation that happened during the formation of our galaxy.

Because the icy bodies are so far from any large planet's gravitational field (30 to 100 AU), they are able to remain on the fringe of the solar system. Some theorists speculate that the large moons Triton and Charon were once members of the Kuiper belt before they were captured by Neptune and Pluto, respectively. These moons and short-period comets have similar physical and chemical properties. Scientists now believe that the Kuiper belt may be home to thousands of objects that have diameters of more than 100 km.

9 According to the information in the passage, which of the following did Gerard Kuiper think were actually icy planetesimals?

A. outer planets
B. comets
C. moons of every planet
D. inner planets

10 What two bodies do some scientists believe were once Kuiper belt objects?

F. Neptune and Charon
G. Neptune and Pluto
H. Triton and Neptune
I. Triton and Charon

11 What did the moon Triton orbit before it was captured by the gravity of Neptune?

A. the sun **C.** the solar system
B. Pluto **D.** Charon

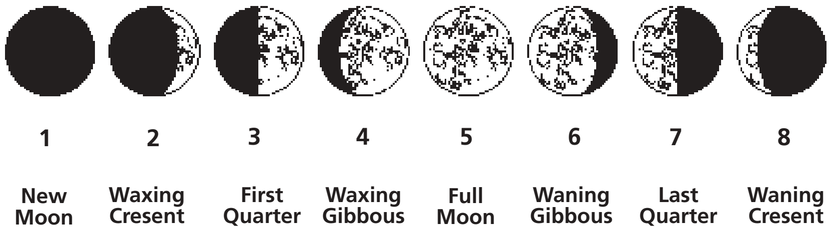
12 Why did it take until the middle of the 20th century for astronomers to discover the presence of the Kuiper belt?

Interpreting Graphics

***Directions (13–16):* For *each* question below, record the correct answer on a separate sheet of paper.**

The diagram below shows the waxing and waning of the moon. Use this diagram to answer questions 13 and 14.

Phases of the Moon in the Northern Hemisphere



13 How would the appearance of the moon in the Southern Hemisphere be different from its appearance in the Northern Hemisphere?

A. The phases of the moon would appear exactly the same.
B. The Southern Hemisphere would see a full moon when the Northern Hemisphere sees a new moon.
C. The moon would wax from left to right instead of from right to left.
D. The Southern Hemisphere would see a waxing moon when the Northern Hemisphere sees a waning moon.

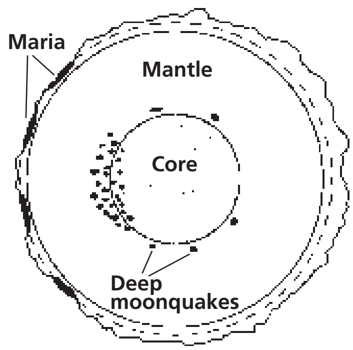
14 What part of the moon is facing Earth during the new moon in stage 1?

F. the near side
G. the far side
H. the north pole
I. the south pole

15 The word *wax* means "to grow larger," while *wane* means "to grow smaller." If the lighted portion of a waxing crescent is the same size as that of a waning crescent, why do you think these terms are used?

The diagram below shows data about the interior structure of the moon. Use this diagram to answer question 16.

Structure of the Moon



16 Where is the crust of the moon the thickest?

A. at the poles
B. at the equator
C. on the near side
D. on the far side

Test TIP

Test questions are not necessarily arranged in order of difficulty. If you are unable to answer a question, mark it and move on to other questions.

Chapter 28 **Skills Practice Lab**

Objectives

- **Calculate** the value of a constant, K.
- **Explain** how Kepler's law of periods explains orbits of moons of Jupiter.

Materials

calculator
metric ruler

Galilean Moons of Jupiter

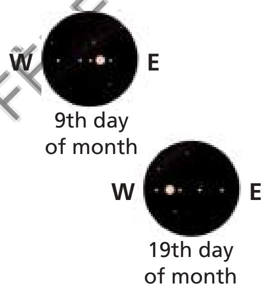
Kepler's third law of motion—the law of periods—explains the relationship between a planet's distance from the sun and the planet's period (the time required to make one revolution around the sun.) According to the law of periods, the cube of the average distance of the planet from the sun is proportional to the square of the planet's period. Kepler's third law can be expressed mathematically as $K \times a^3 = p^2$, in which a is the average distance from the sun, p is the period, and K is a constant. Kepler's third law also may be applied to moons orbiting a planet, in which a is the average distance of a moon to the planet and p is the moon's period. In this activity, you will verify that the orbital motions of Jupiter's moons obey Kepler's third law.

PROCEDURE

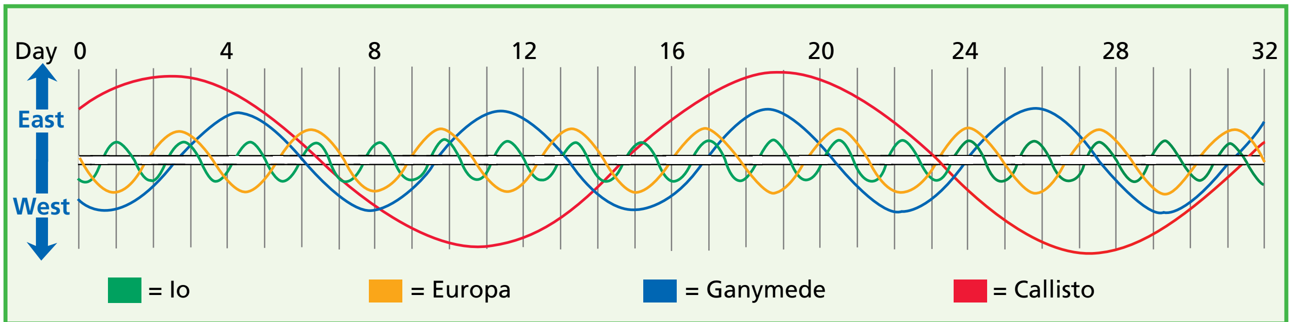
1. Two telescope eyepiece views at the left show how Jupiter and its four largest, or Galilean, moons appear through a telescope on Earth at midnight on the 9th and 19th day of a month. Compare these illustrations with the chart below, which shows the path of each moon as it orbits Jupiter during the same month.
   a. List the days when each of Jupiter's moons crosses in front of the planet.
   b. List the days when each of the moons is behind Jupiter.

2. Use the data in the table on the next page to test Kepler's third law. Calculate p^2 and a^3 for each of the planets. Record your results in a table of your own. Then, calculate K for each planet by using Kepler's third law, $K = p^2/a^3$. Record your results in a similar table.

3. Draw Jupiter and its moons as they would appear from Earth at midnight on the 2nd and 26th of the month.



Step 1 The central horizontal band on the chart below represents Jupiter. When a moon's path crosses in front of this band, the moon is in front of the planet. When a moon's path crosses behind this band, the moon is behind Jupiter.



4. Draw Jupiter's moons on the first day of the month that all four moons are on the same side of the planet. Identify the date.

5. Give a date when only two moons will be visible. Name the two visible moons.

6. Follow each moon's motion on the chart. Find the length of time, in Earth days, required for each moon to orbit Jupiter. To do this, measure the time between two points when the moon is in exactly the same position on the same side of Jupiter. Record your answers in a table listing the moons, p (in Earth days), a (in mm), p^2, a^3, and K.

7. Measure the scale distance between the maximum outward swing of each moon and the center of Jupiter in millimeters. Record your answers in your table.

8. Square each period measurement, and record the answer in your table. Cube each distance measurement, and record the answer.

9. Use your results to test Kepler's third law. Because $K = p^2/a^3$, divide p^2 by a^3 for each moon to find K. Record your results in your table.

Kepler's Third Law

Planet	p (in Earth years)	a (in billions of km)	a^3	p^2	K
Mercury	0.24	0.058			
Venus	0.62	0.108			
Earth	1	0.150			
Mars	1.88	0.228			
Jupiter	11.86	0.778			
Saturn	29.46	1.427			
Uranus	83.8	2.871			
Neptune	163.7	4.497			
Pluto	248.6	5.914			

DO NOT WRITE IN THIS BOOK

ANALYSIS AND CONCLUSION

1. **Analyzing Events** Will you see all four of Jupiter's largest moons each time you look at Jupiter through a telescope or binoculars? Explain your answer.

2. **Making Inferences** If you look at Jupiter's moons through a telescope, they look like dots. If you had no charts, how could you identify each moon?

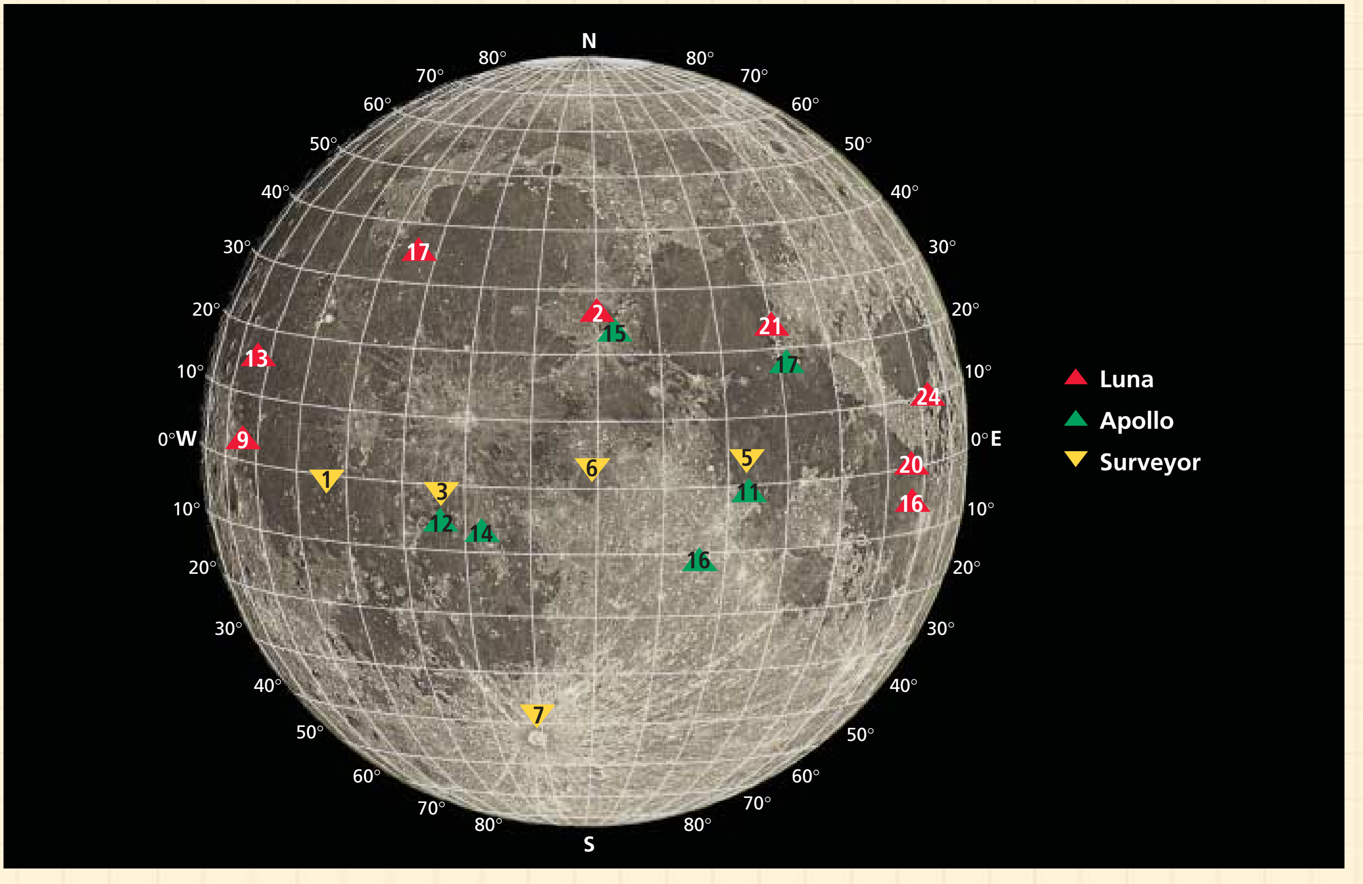
3. **Drawing Conclusions** After you solve for K for each moon, study your results. Is K a constant for the moons of Jupiter? Explain your answer.

Extension

1. **Making Calculations** Recalculate the values of K for the planets by using astronomical units instead of kilometers. How does this affect the amount of variation in the value of the constant?

MAPS in Action

Lunar Landing Sites



Map Skills Activity

This map shows the surface of the near side of the moon and the landing sites of both lunar missions that had crews and lunar missions that did not have crews. Most Surveyor missions took place before the Apollo missions. The Luna missions were launched by the former Soviet Union. Use the map to answer the questions below.

1. **Using the Key** How many Luna missions landed on the moon?
2. **Using the Key** How many Surveyor missions landed on the moon's southern hemisphere?
3. **Analyzing Data** How many Apollo missions landed close to Surveyor mission landing sites?
4. **Making Comparisons** At which areas of latitude are no landing sites located?
5. **Making Comparisons** In what 10° range of latitude are most landing sites located?
6. **Inferring Relationships** Based on the locations of most landing sites, what surface features do you think interested scientists?
7. **Identifying Trends** Many of the missions to the moon used radio communications. Radio communications require a clear path between the transmitter and receiver. Taking these facts into consideration, how many landing sites would you expect to find on the far side of the moon? Explain your answer.

SCIENCE AND TECHNOLOGY

Mining on the Moon

Since astronauts landed on the moon in 1969, scientists have been working toward permanent lunar bases. The biggest obstacle is the cost of transporting construction materials and life-support systems. So, scientists are developing ways to produce the materials by mining the moon's own natural resources.

Moon Mining Methods

One of the promising mining methods uses electrolysis, a process in which an electrical current is passed through a substance to change the chemical composition of the substance. Scientists hope to use electrolysis to extract iron and oxygen from lunar rocks. To test the procedure, scientists created a silicate rock like the rocks that are common on the moon. After melting the rock, they passed an electrical current through the molten rock, which caused iron and oxygen to separate from the other elements. On the moon, the extracted iron could be used to manufacture steel, and the oxygen could support human life.

Researchers also imagine using a solar-powered satellite to provide energy for everything from lunar mining to life-support systems. The satellite might use a solar concentrator and lasers to beam energy to the moon's surface. There, the laser light would be converted into electricity.

▲ Lunar mining operations might look something like this.

Ice Mines

Another important substance that might be mined on the moon is water in the form of ice. Many scientists think that the amount of ice that has been discovered in the craters near the poles could be of practical use. This ice was discovered where the crater rims have shielded the ice from the sun's rays and prevented it from melting.

◀ Apollo astronauts discovered valuable materials on the moon.

Mining the moon may not be possible for many years to come. But scientists continue to develop the technology to make it possible. In addition to developing the necessary technology, many more geological studies of the moon are necessary before undertaking such a project. The European Space Agency's *SMART-1* spacecraft, launched in 2003, is one such mission. If mining the moon were profitable, it would help secure funding for future space exploration by opening the door to private commercial ventures.

Extension

1. **Making Inferences** Why would solar energy be important for a lunar mining operation?

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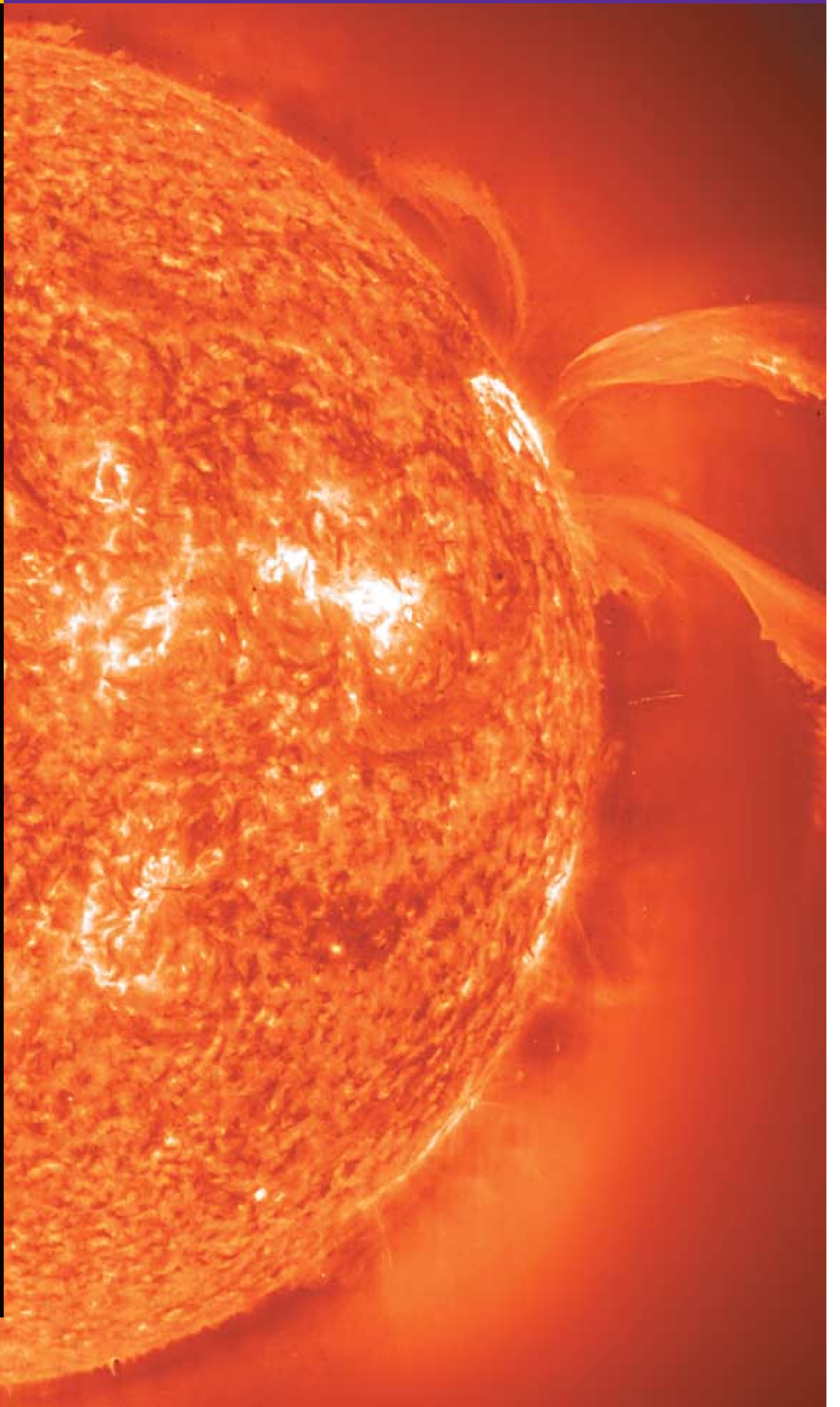
Chapter 29 The Sun



Sections

What You'll Learn

- How the sun's interior differs from its surface layers
- How sunspots and other solar activity vary during an 11-year cycle

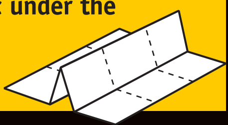
Why It's Relevant

The sun is the energy source that fuels most life on Earth. Understanding how the sun's energy affects Earth helps people understand how Earth interacts with the sun.

PRE-READING ACTIVITY

FOLDNOTES

Table Fold Before you read this chapter, create the **FoldNote** entitled "Table Fold" described in the Skills Handbook section of the Appendix. Label the columns of the table fold with "Characteristics of the sun," "Energy of the sun," "Composition of the sun," and "Layers of the sun." As you read the chapter, write examples of each topic under the appropriate column.



▶ Huge plumes of hot gas that are many times the size of Earth, called *prominences,* are occasionally visible in the sun's atmosphere. The hottest parts of the sun shown in this false-color image are white, and the coolest areas are dark red.

Section 1 Structure of the Sun

Throughout much of human history, people thought that the sun's energy came from fire. People knew that burning a piece of coal or wood produced heat and light. They assumed that the sun, too, burned some type of fuel to produce its energy. But less than 100 years ago, scientists discovered that the source of the sun's energy is quite different from fire.

OBJECTIVES

- **Explain** how the sun converts matter into energy in its core.
- **Compare** the radiative and convective zones of the sun.
- **Describe** the three layers of the sun's atmosphere.

KEY TERMS

nuclear fusion
radiative zone
convective zone
photosphere
chromosphere
corona

The Sun's Energy

The sun appears to the unaided eye as a dazzling, brilliant ball that has no distinct features. Because the sun's brightness can damage your eyes if you look directly at the sun, astronomers look at the sun only through special filters. Astronomers often use other specialized scientific instruments to study the sun.

Composition of the Sun

Scientists break up the sun's light into a spectrum (plural, *spectra*) by using a device called a *spectrograph*. Dark lines form in the spectra of stars when gases in the stars' outer layers absorb specific wavelengths of the light that passes through the layers. The temperature of these outer layers determines which gases produce visible spectral lines. By studying the spectrum of a star, scientists can determine the amounts of elements that are present in a star's atmosphere. They can also deduce the temperature, density, and pressure of the gas. Because each element produces a unique pattern of spectral lines, astronomers can match the spectral lines of starlight to those of Earth's elements, as shown in **Figure 1,** and identify the elements in the star's atmosphere.

Both hydrogen and helium occur in the sun. About 75% of the sun's mass is hydrogen, and hydrogen and helium together make up about 99% of the sun's mass. The sun's spectrum reveals that the sun contains traces of almost all other chemical elements.

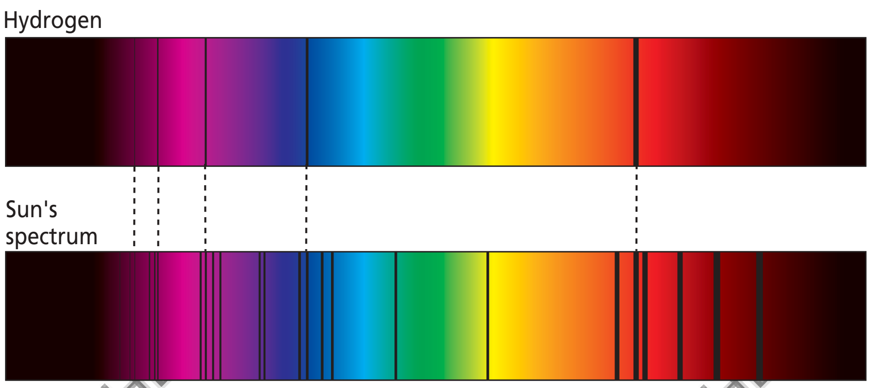
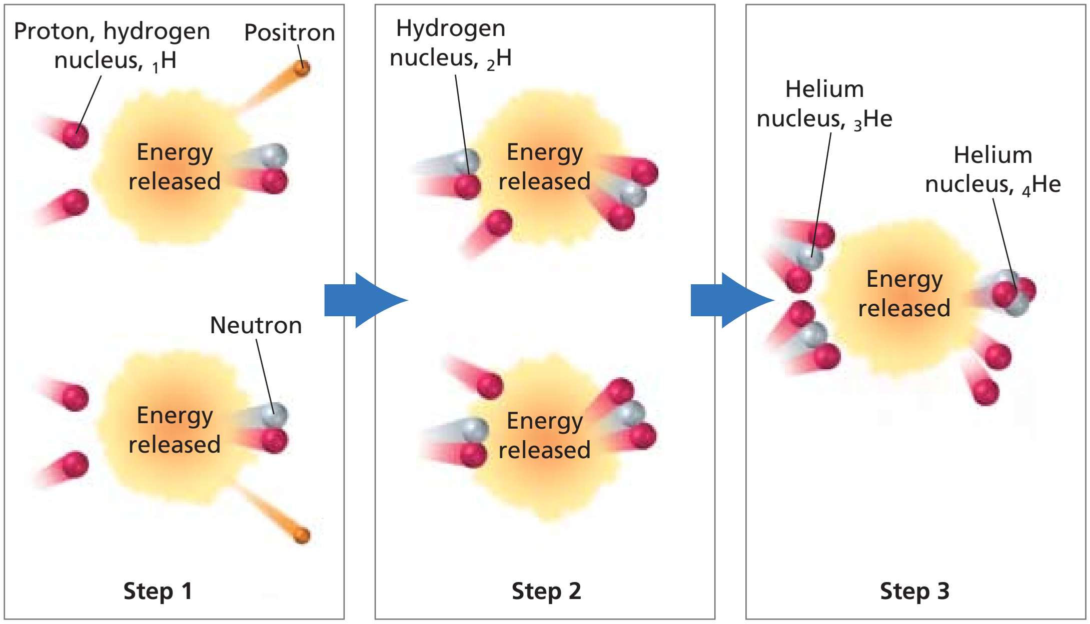


Figure 1 ▶ When light passes through hydrogen gas and then through a slit in a prism, dark lines appear in the spectrum. Hydrogen and lines from other elements in the solar spectrum are shown in the bottom spectrograph. ***How many lines are not accounted for by the presence of hydrogen in the sun's atmosphere?***

Figure 2 ▶ In the core of the sun, the nuclei of hydrogen atoms fuse to form helium. The fusion process converts mass into energy.



Nuclear Fusion

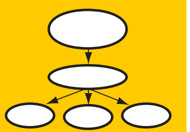
nuclear fusion the process by which nuclei of small atoms combine to form a new, more massive nucleus; the process releases energy

A powerful atomic process known as nuclear fusion occurs inside the sun. **Nuclear fusion** is the process of combining nuclei of small atoms to form more-massive nuclei. Fusion releases huge amounts of energy. Nuclei of hydrogen atoms are the primary fuel for the sun's fusion. A hydrogen atom, the simplest of all atoms, commonly consists of only one electron and one proton. Inside the sun, however, electrons are stripped from the protons by the sun's intense heat.

Nuclear fusion produces most of the sun's energy and consists of three steps, as shown in **Figure 2.** In the first step, two hydrogen nuclei, or *protons,* collide and fuse. In this step, the positive charge of one of the protons is neutralized as that proton emits a particle called a *positron*. As a result, the proton becomes a neutron and changes the original two protons into a proton-neutron pair. In the second step, another proton combines with this proton-neutron pair to produce a nucleus made up of two protons and one neutron. In the third step, two nuclei made up of two protons and one neutron collide and fuse. As this fusion happens, two protons are released. The remaining two protons and two neutrons are fused together and form a helium nucleus. During each step of the reaction, energy is released.

Graphic Organizer **Chain-of-Events Chart**

Create the Graphic Organizer entitled "Chain-of-Events Chart" described in the Skills Handbook section of the Appendix. Then, fill in the chart with details about each step of the process of nuclear fusion.



The Final Product

One of the final products of the fusion of hydrogen in the sun is always a helium nucleus. The helium nucleus has about 0.7% less mass than the hydrogen nuclei that combined to form it do. The lost mass is converted into energy during the series of fusion reactions that forms helium. The energy released during the three steps of nuclear fusion causes the sun to shine and gives the sun its high temperature.

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Mass Changing into Energy

The sun's energy comes from fusion, and the mass that is lost during fusion becomes energy. In 1905, the physicist Albert Einstein, then an unknown patent-office worker, proposed that a small amount of matter yields a large amount of energy. At the time, the existence of nuclear fusion was unknown. In fact, scientists had not yet discovered the nucleus of the atom. Einstein's proposal was part of his special theory of relativity. This theory included the equation $E = mc^2$. In this equation, E represents energy produced; m represents the mass, or the amount of matter, that is changed; and c represents the speed of light, which is about 300,000 km/s. Einstein's equation can be used to calculate the amount of energy produced from a given amount of matter.

By using Einstein's equation, astronomers were able to explain the huge quantities of energy produced by the sun. The sun changes more than 600 million tons of hydrogen into helium every second. Yet this amount of hydrogen is small compared with the total mass of hydrogen in the sun. During fusion, a type of subatomic particle, called a *neutrino,* is given off. Neutrinos escape the sun and reach Earth in about eight minutes. Studies of these particles indicate that the sun is fueled by the fusion of hydrogen into helium. One apparatus that collects these particles is shown in **Figure 3.** Elements other than hydrogen can fuse, too. In stars that are hotter than the sun, energy is produced by fusion reactions of the nuclei of carbon, nitrogen, and oxygen.

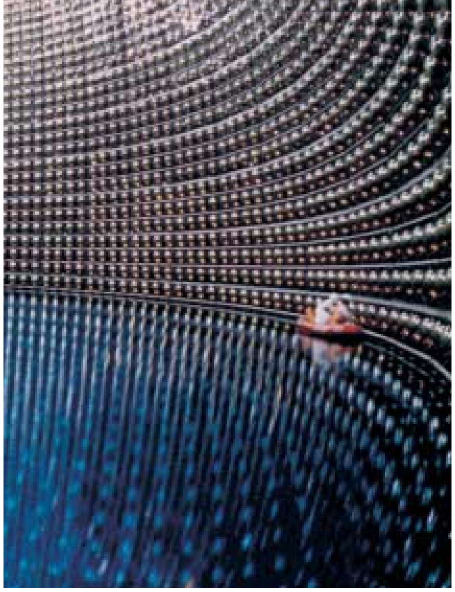

Figure 3 ▶ In Japan, this giant tank of pure water, which was only partly filled when the photo was taken, captures subatomic particles that fly out of the sun during nuclear fusion.

Reading Check **How did the equation $E = mc^2$ help scientists understand the energy of the sun? (See the Appendix for answers to Reading Checks.)**

QuickLAB 5 min

Modeling Fusion

Procedure

1. Mark six coins by using a marker or wax pencil. Put a *P* for "proton" on the head side of each coin and an *N* for "neutron" on the tail side of the coins.
2. Place two coins P-side up. These two protons each represent hydrogen's simplest isotope, H. Model the fusion of these two H nuclei by placing them such that their edges touch. When they touch, flip one of them to be N-side up. This flip represents a proton becoming a neutron during fusion. The resulting nucleus, which consists of one proton and one neutron, represents the isotope hydrogen-2, ^{2}H.
3. To model the next step of nuclear fusion, place a third coin, P-side up, against the ^{2}H nucleus from step 2. This forms the isotope helium-3, or ^{3}He.
4. Repeat steps 2 and 3 to form a second ^{3}He nucleus.
5. Next, model the fusion of two ^{3}He nuclei. Move the two ^{3}He nuclei formed in step 3 so that their edges touch. When the two ^{3}He nuclei touch, move two of the protons in the two ^{3}He nuclei away from the other four particles. These four particles form a new nucleus: helium-4, or ^{4}He.

Analysis

1. Large amounts of energy are released when nuclei combine. How many energy-producing reactions did you model?
2. Create a diagram that shows the formation of ^{4}He.

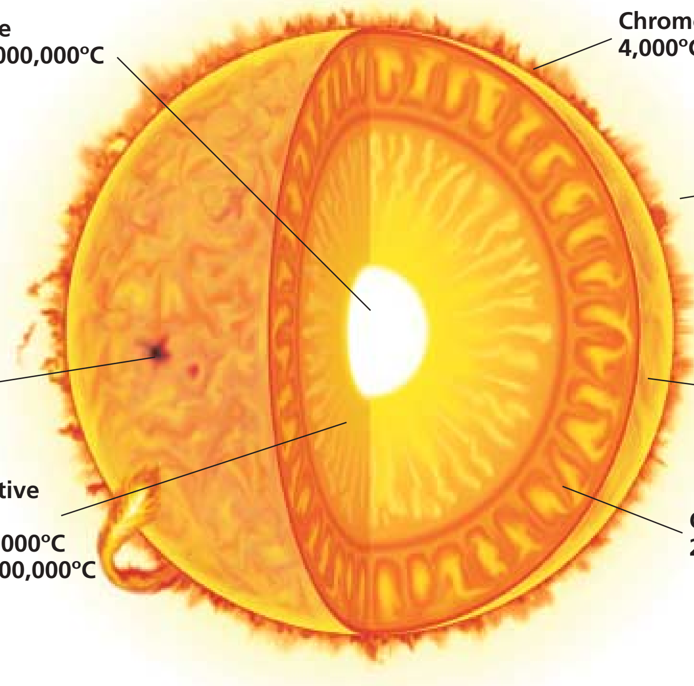

Figure 4 ▶ Energy released by fusion reactions in the core slowly works its way through the layers of the sun by the processes of radiation and convection.

QuickLAB 20 min

The Size of Our Sun

Procedure

1. Using a **compass**, draw a large circle near the edge of a piece of **butcher paper** to represent the sun.
2. Measure the diameter (D) of your "sun."
3. Calculate the size of Earth and Jupiter, and compare the sizes with the size of the sun in step 1 by using the following values:
   $D(\text{sun}) = 1.4 \times 10^9$ m
   $D(\text{Jupiter}) = 1.4 \times 10^8$ m
   $D(\text{Earth}) = 1.3 \times 10^7$ m
4. Now, draw Earth and Jupiter to scale on your model.

Analysis

1. The diameter of the sun's core is about 175,000,000 m. How does size of the core compare with that of Earth and Jupiter?

The Sun's Interior

Scientists can't see inside the sun. But computer models have revealed what the invisible layers may be like. In recent years, careful studies of motions on the sun's surface have supplied more detail about what is happening inside the sun. The parts of the sun are shown in **Figure 4.**

The Core

At the center of the sun is the core. The core makes up 25% of the sun's total diameter of 1,390,000 km. The temperature of the sun's core is about 15,000,000°C. No liquid or solid can exist at such a high temperature. The core, like the rest of the sun, is made up entirely of ionized gas. The mass of the sun is 300,000 times the mass of Earth. Because of the sun's large mass, the pressure from the sun's material is so great that the center of the sun is more than 10 times as dense as iron.

The enormous pressure and high temperature of the sun's core cause the atoms to separate into nuclei and electrons. On Earth, atoms generally consist of a nucleus surrounded by one or more electrons. Within the core of the sun, however, the energy and pressure strip electrons away from the atomic nuclei. The nuclei have positive charges, so they tend to push away from each other. But the high temperature and pressure force the nuclei close enough to fuse. The most common nuclear reaction that occurs inside the sun is the fusion of hydrogen into helium.

The Radiative Zone

Before reaching the sun's atmosphere, the energy produced in the core moves through two zones of the sun's interior. The zone surrounding the core is called the **radiative zone.** The temperature in this zone ranges from about 2,000,000°C to 7,000,000°C. In the radiative zone, energy moves outward in the form of electromagnetic waves, or radiation.

radiative zone the zone of the sun's interior that is between the core and the convective zone and in which energy moves by radiation

convective zone the region of the sun's interior that is between the radiative zone and the photosphere and in which energy is carried upward by convection

photosphere the visible surface of the sun

The Convective Zone

Surrounding the radiative zone is the **convective zone,** where temperatures are about 2,000,000°C. Energy produced in the core moves through this zone by convection. *Convection* is the transfer of energy by moving matter. On Earth, boiling water carries energy upward by convection. In the sun's convective zone, hot gases carry energy to the sun's surface. As the hot gases move outward and expand, they lose energy. The cooling gases become denser than the other gases and sink to the bottom of the convective zone. There, the cooled gases are heated by the energy from the radiative zone and rise again. Thus, energy is transferred to the sun's surface as the gases rise and sink.

The Sun's Atmosphere

Surrounding the convective zone is the sun's atmosphere. Although the sun is made of gases, the term *atmosphere* refers to the uppermost region of solar gases. This region has three layers—the photosphere, the chromosphere, and the corona.

The Photosphere

The innermost layer of the solar atmosphere is the **photosphere.** *Photosphere* means "sphere of light." The photosphere is made of gases that have risen from the convective zone. The temperature in the photosphere is about 6,000°C. Much of the energy given off from the photosphere is in the form of visible light. The layers above the photosphere are transparent, so the visible light is the light that is seen from Earth. A photo of the sun's photosphere is shown in **Figure 5.** The dark spots are cool areas of about 3,800°C and are called *sunspots*.

Reading Check **What layers make up the sun's atmosphere? (See the Appendix for answers to Reading Checks.)**

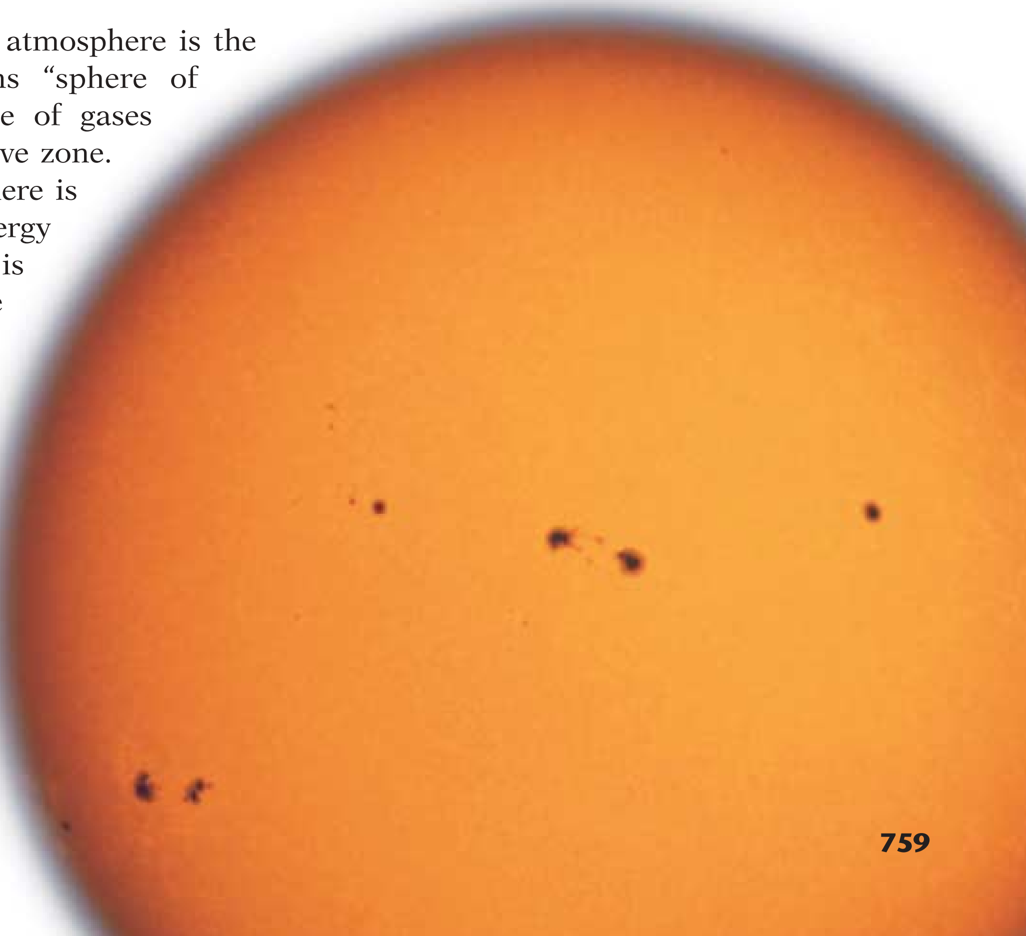

Figure 5 ▶ The photosphere is referred to as the sun's surface because this layer is the visible surface of the sun.

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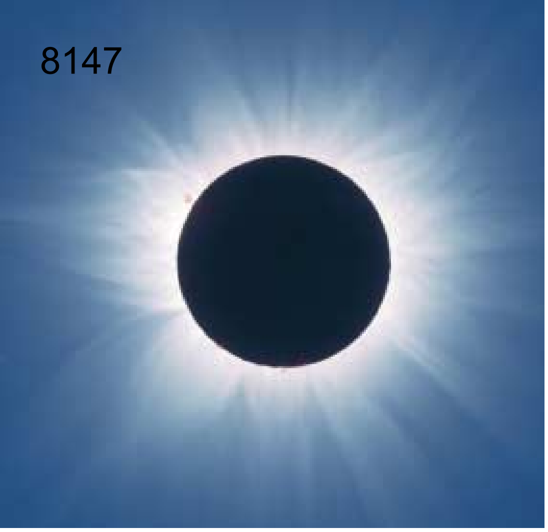

Figure 6 ▶ The corona of the sun becomes visible during a total solar eclipse.

The Chromosphere

Above the photosphere lies the **chromosphere**, or color sphere. The chromosphere is a thin layer of gases that glows with reddish light that is typical of the color given off by hydrogen. The chromosphere's temperature ranges from 4,000ºC to 50,000ºC. The gases of the chromosphere move away from the photosphere. In an upward movement, gas regularly forms narrow jets of hot gas that shoot outward to form the chromosphere and then fade away within a few minutes. Some of these jets reach heights of 16,000 km.

Spacecraft study the sun from above Earth's atmosphere. These spacecraft can detect small details on the sun because they measure wavelengths of light that are blocked by Earth's atmosphere. Movies made from these spacecraft images show how features on the sun rise, change, and sometimes twist.

chromosphere the thin layer of the sun that is just above the photosphere and that glows a reddish color during eclipses

corona the outermost layer of the sun's atmosphere

The Sun's Outer Parts

The outermost layer of the sun's atmosphere is the **corona** (kuh ROH nuh), or crown. The corona is a huge region of gas that has a temperature above 1,000,000ºC. The corona is not very dense, but its magnetic field can stop most subatomic particles from escaping into space. However, electrons and electrically charged particles called *ions* do stream out into space as the corona expands. These particles make up the *solar wind,* which flows outward from the sun to the rest of the solar system.

The chromosphere and the corona are normally not seen from Earth because the sky during the day is too bright. Occasionally, however, the moon moves between Earth and the sun and blocks out the light of the photosphere. The sky darkens, and the corona becomes visible, as shown in **Figure 6.**

Section 1 Review

1. **Describe** how scientists use spectra to determine the composition of stars.
2. **Identify** the two elements that make up most of the sun.
3. **Identify** the end products of the nuclear fusion process that occurs in the sun.
4. **Explain** how the sun converts matter into energy in its core.
5. **Compare** the radiative and convective zones of the sun.
6. **Describe** the three layers of the sun's atmosphere.
7. **Explain** why the sun's corona can be seen during an eclipse but not at other times.

CRITICAL THINKING

8. **Making Inferences** Describe whether the amount of hydrogen in the sun will increase or decrease over the next few million years. Explain your reasoning.
9. **Analyzing Ideas** Why does fusion occur in the sun's core but not in other layers?
10. **Predicting Consequences** What might happen to the solar wind if the sun lost its corona?

CONCEPT MAPPING

11. Use the following terms to create a concept map: *sun, hydrogen, helium, nuclear fusion, core, radiative zone,* and *convective zone.*

Section 2 Solar Activity

The gases that make up the sun's interior and atmosphere are in constant motion. The energy produced in the sun's core and the force of gravity combine to cause the continuous rising and sinking of gases. The gases also move because the sun rotates on its axis. Because the sun is a ball of hot gases rather than a solid sphere, not all locations on the sun rotate at the same speed. Places close to the equator on the surface of the sun take 25.3 Earth days to rotate once. Points near the poles take 33 days to rotate once. On average, the sun rotates once every 27 days.

OBJECTIVES

- **Explain** how sunspots are related to powerful magnetic fields on the sun.
- **Compare** prominences, solar flares, and coronal mass ejections.
- **Describe** how the solar wind can cause auroras on Earth.

KEY TERMS

sunspot
prominence
solar flare
coronal mass ejection
aurora

Sunspots

The movement of gases within the sun's convective zone and the movements caused by the sun's rotation produce magnetic fields. These magnetic fields cause convection to slow in parts of the convective zone. Slower convection causes a decrease in the amount of gas that is transferring energy from the core of the sun to these regions of the photosphere. In some places, the magnetic field is thousands of times stronger than it is in other places. Because less energy is being transferred, these regions of the photosphere are up to 3,000°C cooler than surrounding regions.

Although they still shine brightly, these cooler areas of the sun appear darker than the areas that surround them do. These cool, dark areas of gas within the photosphere are called **sunspots.** The photosphere has a grainy appearance called *granulation.* The area around the sunspots shown in **Figure 1** has visible granulation. A large sunspot can have a diameter of more than 100,000 km, which is several times the diameter of Earth.

sunspot a dark area of the photosphere of the sun that is cooler than the surrounding areas and that has a strong magnetic field

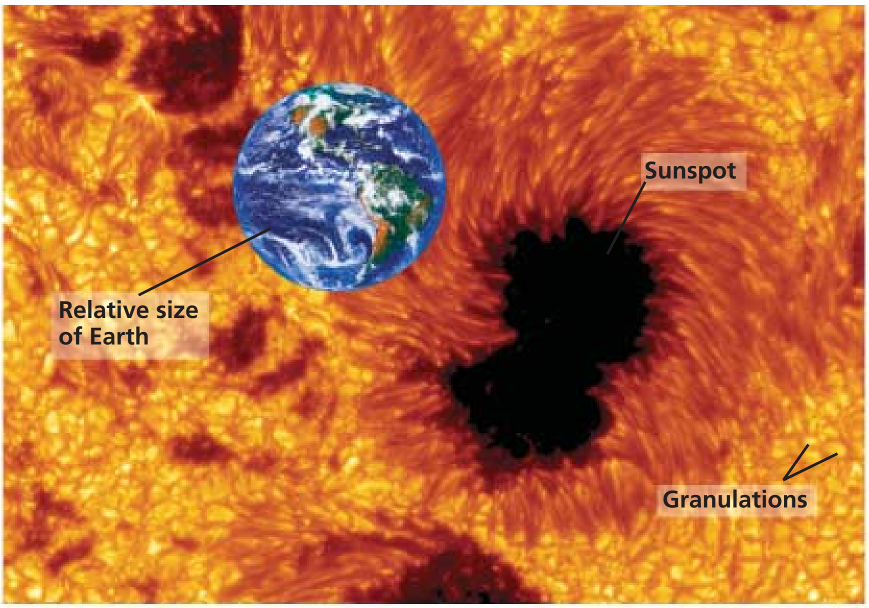

Figure 1 ▶ The diameter of this large sunspot is bigger than Earth's diameter. This image shows the granulation on the sun's surface.

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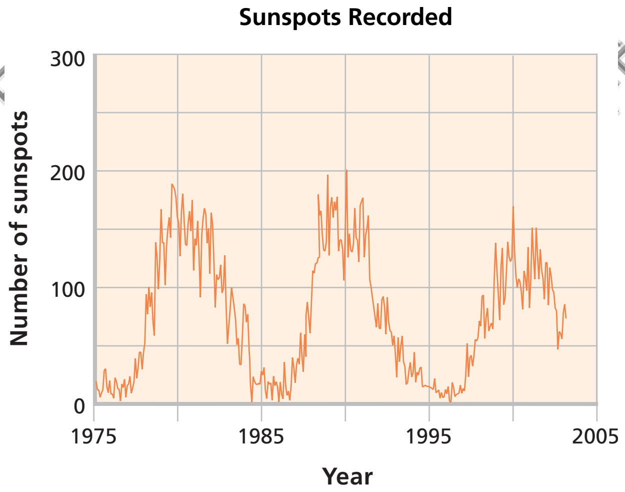

Figure 2 ▶ The sunspot cycle lasts an average of 11 years. ***When will the next high point in the cycle occur?***

The Sunspot Cycle

Astronomers have carefully observed sunspots for hundreds of years. Observations of sunspots showed astronomers that the sun rotates. Later, astronomers observed that the numbers and positions of sunspots vary in a cycle that lasts about 11 years.

A sunspot cycle begins when the number of sunspots is very low but begins to increase. Sunspots initially appear in groups about midway between the sun's equator and poles. The number of sunspots increases over the next few years until it reaches a peak of 100 or more sunspots. Then, sunspots at higher latitudes slowly disappear, and new ones appear closer to the sun's equator. **Figure 2** shows that after the peak, the number of sunspots begins to decrease until it reaches a minimum. Another 11-year cycle begins when the number of sunspots begins to increase again.

Solar Ejections

Many other solar activities are affected by the sunspot cycle. The *solar-activity cycle* is caused by the changing solar magnetic field. This cycle is characterized by increases and decreases in various types of solar activity, including solar ejections. Solar ejections are events in which the sun emits atomic particles. These events include prominences, solar flares, and coronal mass ejections.

Connection to ASTRONOMY

Total Solar Irradiance

Astronomers once thought that the sun's energy output remained steady. They called the amount of solar energy that a square centimeter of the top of Earth's atmosphere receives each second the *solar constant*. Earth's atmosphere causes an amount of energy that is less than the solar constant to reach Earth's surface.

Careful spacecraft observations made outside Earth's atmosphere have shown, however, that the solar constant isn't constant. Observations made by the Solar Maximum Mission first showed the effect. The solar constant is now being followed with special equipment on the Solar and Heliospheric Observatory (SOHO), the Active Cavity Radiometer Irradiance Monitor satellite (ACRIMSAT), and the Solar Radiation and Climate Experiment (SORCE) satellite. The ACRIMSAT and the SORCE satellite measure the entire range of solar radiation. Because this value changes, it is now officially called the *total solar irradiance* instead of the *solar constant*. *Irradiance* is simply the amount of energy that falls on a square centimeter of Earth each second. *Total* means that the whole spectrum of sunlight is included, not just the visible part.

The total solar irradiance varies by about 0.2% over the 11-year sunspot cycle. It is highest when the sunspot cycle is at its maximum. Individual sunspots, however, can temporarily block a small amount of the energy that comes from the sun and thus lower the total solar irradiance.

The SORCE satellite is being used to follow total solar irradiance.

Prominences

The magnetic fields that cause sunspots also create other disturbances in the sun's atmosphere. Great clouds of glowing gases, called **prominences**, form huge arches that reach high above the sun's surface. Each solar prominence follows curved lines of magnetic force from a region of one magnetic polarity to a region of the opposite magnetic polarity. Some prominences may last for several weeks, while others may erupt and disappear in hours. The gas in prominences is very hot and is commonly associated with the chromosphere.

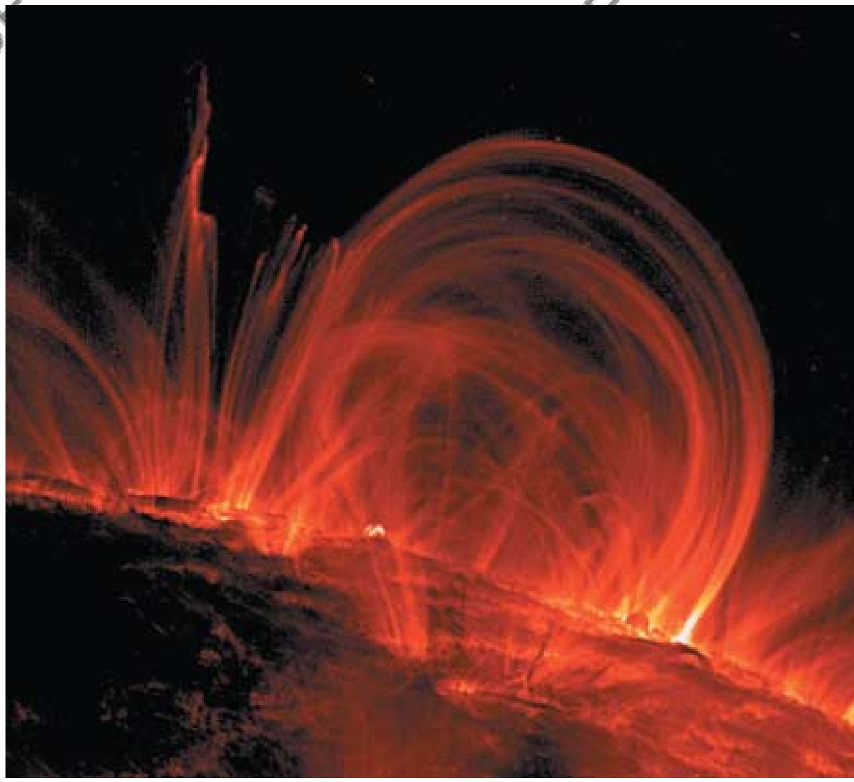

Figure 3 ▶ A loop of coronal gas can arch half a million kilometers or more above the sun's surface.

Solar Flares

The most violent of all solar disturbances is a **solar flare**, a sudden outward eruption of electrically charged particles, such as electrons and protons. The trigger for these eruptions is unknown. However, scientists know that solar flares release the energy stored in the strong magnetic fields of sunspots. This release of energy can lead to the formation of coronal loops, such as the one shown in **Figure 3.**

Solar flares may travel upward thousands of kilometers within minutes, but few eruptions last more than an hour. During a peak in the sunspot cycle, 5 to 10 solar flares may occur each day. The temperature of the gas in solar flares may reach 20,000,000°C.

prominence a loop of relatively cool, incandescent gas that extends above the photosphere

solar flare an explosive release of energy that comes from the sun and that is associated with magnetic disturbances on the sun's surface

coronal mass ejection a part of coronal gas that is thrown into space from the sun

Coronal Mass Ejections

Some of the particles from a solar flare escape into space. These particles increase the strength of the solar wind. Particles also escape into space as **coronal mass ejections,** or parts of the corona that are thrown off the sun. As the gusts of particles strike Earth's *magnetosphere*, or the space around Earth that contains a magnetic field, the particles can generate a sudden disturbance in Earth's magnetic field. These disturbances are called *geomagnetic storms*. Although several small geomagnetic storms may occur each month, the average number of severe storms is less than one per year.

Geomagnetic storms have been known to interfere with radio communications on Earth. The high-energy particles that circulate in Earth's outer atmosphere during geomagnetic storms can also damage satellites. They can also lead to blackouts when power lines become overloaded. Not all solar activity is so dramatic, but the activity of the sun affects Earth every day.

Reading Check **How do coronal mass ejections affect communications on Earth? (See the Appendix for answers to Reading Checks.)**

MATHPRACTICE

Magnetic Fields
Magnetic fields on the sun differ greatly from each other. Field densities at the poles are 0.001 teslas (T), while field densities near sunspots are up to 0.3 T. How many times the densities of fields at the sun's poles are densities of fields near sunspots?

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Figure 4 ▶ Auroras, such as these over Canada, can fill the entire sky. When high-energy particles strike oxygen atoms in the upper atmosphere, green curtains form. When low-energy particles strike oxygen atoms, red curtains form.

Auroras

On Earth, a spectacular effect of the interaction between the solar wind and Earth's magnetosphere is the appearance in the sky of bands of light called **auroras** (aw RAWR uhz). **Figure 4** shows an example of an aurora. Auroras are usually seen close to Earth's magnetic poles because electrically charged particles are guided toward Earth's magnetic poles by Earth's magnetosphere. The electrically charged particles strike the atoms and gas molecules in the upper atmosphere and produce colorful sheets of light. Depending on which pole they are near, auroras are called *northern lights*—or *aurora borealis* (aw RAWR uh BAWR ee AL is)—or *southern lights*—or *aurora australis*.

Auroras normally occur between 100 and 1,000 km above Earth's surface. They are most frequent just after a peak in the sunspot cycle, especially after solar flares occur. Across the northern contiguous United States, auroras are visible about five times per year. In Alaska, however, people can see auroras almost every clear, dark night. Astronauts in orbit can also look down on Earth and see auroras. But Earth is not the only planet that has auroras. Spacecraft have recorded auroras on Jupiter and Saturn.

aurora colored light produced by charged particles from the solar wind and from the magnetosphere that react with and excite the oxygen and nitrogen of Earth's upper atmosphere; usually seen in the sky near Earth's magnetic poles

Section 2 Review

1. **Explain** why sunspots are cooler than surrounding areas on the sun's surface.
2. **Identify** the number of sunspots that are on the sun during the peak of the sunspot cycle.
3. **Summarize** how the latitude of sunspots varies during the sunspot cycle.
4. **Explain** how prominences are different from solar flares.
5. **Summarize** the cause of auroras on Earth.

CRITICAL THINKING

6. **Identifying Relationships** How can a sunspot be bright but look dark?
7. **Analyzing Ideas** Why doesn't the whole sun rotate at the same rate?

CONCEPT MAPPING

8. Use the following terms to create a concept map: *sunspot, prominence, solar flare, solar-activity cycle,* and *coronal mass ejection.*

Chapter 29 Highlights

Sections

1 Structure of the Sun

Key Terms

nuclear fusion, 756
radiative zone, 759
convective zone, 759
photosphere, 759
chromosphere, 760
corona, 760

Key Concepts

- The enormous pressure and heat in the sun's core converts matter into energy through the process of nuclear fusion.
- Nuclear fusion combines four hydrogen nuclei to form one helium nucleus.
- Energy from the sun's core moves through the radiative zone and the convective zone before it enters the sun's atmosphere.
- The sun's atmosphere is composed of the photosphere, the chromosphere, and the corona.
- Solar wind forms when electrons and electrically charged particles called *ions* from the corona travel into space.

2 Solar Activity

sunspot, 761
prominence, 763
solar flare, 763
coronal mass ejection, 763
aurora, 764

- Sunspots are caused by powerful magnetic fields in the sun.
- The sunspot cycle is a periodic variation in the number of sunspots and occurs about every 11 years. The sunspot cycle is closely related to the cycles of other solar activity.
- Prominences, solar flares, and coronal mass ejections are examples of solar activity that are caused by changes in the sun's magnetic field.
- Auroras in Earth's polar regions occur when charged particles from the interaction between the solar wind and Earth's magnetosphere collide with atoms and molecules in Earth's atmosphere.

Chapter 29 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *photosphere*
2. *solar flare*
3. *solar wind*
4. *sunspot cycle*

For each pair of terms, explain how the meanings of the terms differ.

5. *chromosphere* and *corona*
6. *photosphere* and *core*
7. *solar flare* and *prominence*
8. *aurora* and *solar wind*

Understanding Key Concepts

9. According to Einstein's theory of relativity, in the formula $E = mc^2$, the *c* stands for
   a. corona.
   b. core.
   c. the speed of light.
   d. the length of time.
10. A nuclear reaction in which atomic nuclei combine is called
    a. fission. c. magnetism.
    b. fusion. d. granulation.
11. The part of the sun in which energy moves from atom to atom in the form of electromagnetic waves is called the
    a. radiative zone. c. solar wind.
    b. convective zone. d. chromosphere.
12. The number of hydrogen atoms that fuse to form a helium atom is
    a. two. c. six.
    b. four. d. eight.
13. The part of the sun that is normally visible from Earth is the
    a. core. c. corona.
    b. photosphere. d. solar nebula.
14. Sunspots are regions of
    a. intense magnetism.
    b. the core.
    c. high temperature.
    d. lighter color.
15. The sunspot cycle repeats about every
    a. month. c. 11 years.
    b. 5 years. d. 19 years.
16. Sudden outward eruptions of electrically charged particles from the sun are called
    a. prominences. c. sunspots.
    b. coronas. d. solar flares.
17. Gusts of solar wind can cause
    a. rotation. c. nuclear fission.
    b. magnetic storms. d. nuclear fusion.
18. *Northern lights* and *southern lights* are other names for
    a. prominences.
    b. auroras.
    c. granulations.
    d. total solar irradiance.

Short Answer

19. What is the outermost layer of the sun?
20. How is the solar activity cycle related to the sunspot cycle?
21. What is unusual about the magnetic field in a sunspot?
22. From what process does the sun gets its energy? What steps does this process follow?
23. Compare two types of solar activity.
24. Describe the corona, and identify when it is visible from Earth.
25. How does the transfer of energy in the radiative zone differ from the transfer of energy in the convective zone?

Critical Thinking

26. Making Comparisons How is the transfer of energy in a pan of hot water similar to the transfer of energy in the sun's convective zone?

27. Making Comparisons Explain how the radiative zone in the sun is similar to the region between the sun and Earth.

28. Making Predictions Predict what would happen to the number of sunspots if parts of the sun's magnetic field suddenly increased in strength.

29. Drawing Conclusions If Earth's magnetosphere shifted so that solar wind was not deflected toward the poles but was deflected toward the equator, what would happen to the area where auroras are most often visible?

30. Analyzing Relationships Magnetic fields create electric currents that can damage electric power grids and interrupt the flow of electricity. How does this information help explain why strong magnetic storms can knock out power in cities?

31. Predicting Consequences How do scientists predict magnetic storms? List two ways that scientists on Earth could help people prepare for a very large magnetic storm.

Concept Mapping

32. Use the following terms to create a concept map: *sun, nuclear fusion, core, radiative zone, convective zone, photosphere,* and *corona.*

Math Skills

33. Making Calculations On average, Earth is 150×10^6 km from the sun. A coronal mass ejection, or CME, can have a speed of 7×10^6 km/h. At this speed, how long would a CME take to reach Earth?

34. Applying Information A peak of the sunspot cycle occurred in the year 2000. In what years will the next two peaks occur?

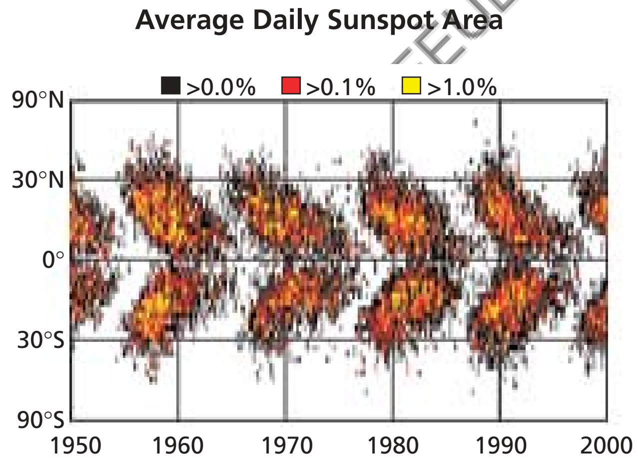
Writing Skills

35. Creative Writing Write a short story that describes an imaginary trip to the center of the sun. Describe each layer and zone through which you would pass.

36. Writing from Research Research the northern lights. Write a short travel brochure that describes when and where to go to see the most spectacular and frequent displays of the auroras.

Interpreting Graphics

The graph below shows how the latitudes of sunspots vary over time. Use the graph to answer the questions that follow.



37. How many complete sunspot cycles are illustrated by the graph?

38. How does the range of latitudes of sunspots change over time? How is this change related to the sunspot cycle?

39. According to the graph, how many sunspots were located at the sun's north pole?

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Chapter 29 Standardized Test Prep

Understanding Concepts

Directions (1–5): **For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1. What is the source of the sun's energy?
   A. nuclear fission reactions that break down massive nuclei to form lighter atoms
   B. nuclear fusion reactions that combine smaller nuclei to form more massive ones
   C. reactions that strip away electrons to form lighter atoms
   D. reactions that strip away electrons to form more massive ones

2. What do electrically charged particles from the sun strike in Earth's magnetosphere to produce sheets of light known as auroras?
   F. gas molecules
   G. dust particles
   H. water vapor
   I. ice crystals

3. Which layer of the sun has the densest material?
   A. the corona
   B. the convection zone
   C. the radiative zone
   D. the core

4. Based on the amount of fuel the sun possessed at its formation, the life span of the sun is thought by scientists to be how long?
   F. 1 billion years
   G. 5 billion years
   H. 10 billion years
   I. 50 billion years

5. The solar activity cycle occurs regularly every
   A. 5 years
   B. 11 years
   C. 16 years
   D. 22 years

Directions (6–7): **For *each* question, write a short response.**

6. In which part of the sun's interior is energy carried to the sun's surface by moving matter?

7. What is the term for the innermost layer of the sun's atmosphere?

Reading Skills

Directions (8–10): **Read the passage below. Then, answer the questions.**

Studying the Sun

Sunlight that has been focused, especially through a magnifying glass, can produce a great amount of thermal energy—enough to start a fire. Imagine focusing the sun's rays by using a magnifying glass that has a diameter of 1.6 m. The resulting heat could easily melt metal. If a conventional telescope were pointed directly at the sun, its parts could melt and become useless.

To avoid a meltdown, the McMath-Pierce telescope uses a special mirror that produces an image of the sun. This mirror directs the sun's rays down a long, diagonal shaft to another mirror, which is located 50 m underground. This second mirror is adjustable, which allows it to focus the sunlight. The sunlight is then directed to a third mirror, which in turn directs the light to an observing room and instrument shaft. This system, while complex, not only protects the sensitive and expensive telescopic equipment but also protects the scientists that use it as well.

8. According to the information in the passage, which of the following statements about solar telescopes is true?
   A. Solar telescopes allow scientists to safely observe the sun.
   B. Solar telescopes do not need mirrors to focus the sun's rays.
   C. All solar telescopes are built 50 m underground.
   D. All solar telescopes are built with a diameter of 1.6 m.

9. Which of the following statements can be inferred from the information in the passage?
   F. Focusing sunlight can help avoid a meltdown.
   G. Unfocused sunlight produces little energy.
   H. A magnifying glass can focus sunlight to produce a great amount of thermal energy.
   I. Mirrors greatly increase the intensity and danger of studying sunlight.

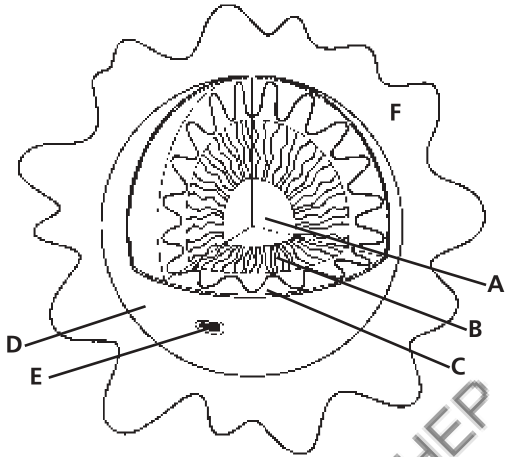
10. Why do scientists have to use specialized equipment to study the sun?

Interpreting Graphics

Directions (11–13): **For *each* question below, record the correct answer on a separate sheet of paper.**

The graphic below shows the structure of the sun. Use this diagram to answer questions 11 and 12.

Structure of the Sun



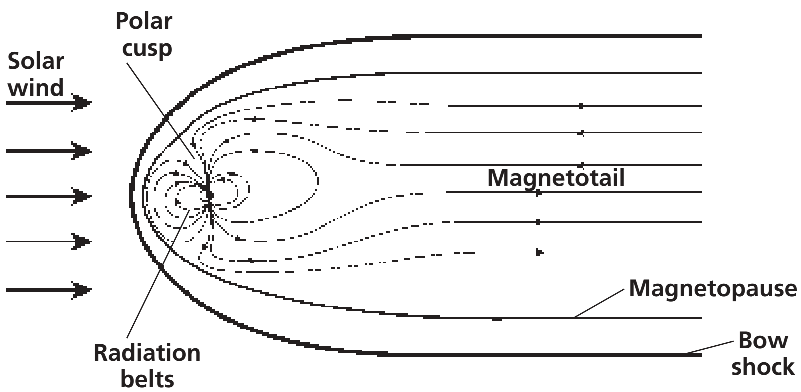
11 Fusion reactions provide power for the stars, such as the sun. In which part of the sun do these fusion reactions take place?

A. layer A
B. layer B
C. layer C
D. layer D

12 What is the term for the dark, cool regions of the sun, which are represented by the letter E on the diagram?

The diagram below shows what happens when Earth's magnetic field interacts with the solar wind. Use this graphic to answer question 13.

Earth's Magnetosphere



13 How does the solar wind affect humans and other living things on Earth, despite the protection provided by the magnetosphere? Use examples to explain your answer.

Test TIP

Choose the best possible answer for each question, even if you think there is another possible answer that is not given.

Chapter 29

Skills Practice Lab

Objectives

- **Estimate** the sun's energy output.
- **USING SCIENTIFIC METHODS** **Evaluate** the differences between known values and experimental values.

Materials

- clay, modeling
- desk lamp with 100 W bulb
- jar, glass, with lid
- metal, sheet, very thin, at least 2 cm × 8 cm
- paint, black, flat finish
- pencil
- ruler, metric
- tape, masking
- thermometer, Celsius

Safety

Energy of the Sun

The sun is, on average, 150 million kilometers away from Earth. Scientists use complicated astronomical instruments to measure the size and energy output of the sun. However, it is possible to estimate the sun's energy by using simple instruments and the knowledge of the relationship between the sun's size and the sun's distance from Earth. In this lab, you will collect energy from sunlight and estimate the amount of energy produced by the sun.

PROCEDURE

1. Construct a solar collector in the following way.
   - **a.** Carefully punch a hole in the jar lid, or use a lid that is already prepared by your teacher.
   - **b.** Shape the piece of sheet metal by gently bending it around a pencil. Bend the edges out so that they form "wings," as shown in the photo. Then, carefully place the metal piece around the thermometer bulb so that it fits snugly. Be careful not to press too hard. **CAUTION** Thermometers are fragile. Do not squeeze the bulb of the thermometer or let the thermometer strike any solid object. Bend the remaining metal outward to collect as much sunlight as possible.
   - **c.** If the sheet metal is not already painted, paint the sheet metal black.
   - **d.** Slip the top of the thermometer through the hole in the jar's lid. On the top and bottom of the lid, mold the clay around the thermometer to hold the thermometer steady. Place the lid on the jar. Adjust the thermometer so that the metal wings are centered in the jar. Then, secure the thermometer and clay to the lid with masking tape.
2. Place the solar collector in sunlight. Tilt the jar so that the sun shines directly on the metal wings. Carefully hold the jar in place. You may want to prop the jar up carefully with books.
3. Watch the temperature reading on the thermometer until it reaches a maximum value or until 5 min has elapsed. Record this value. Allow the collector to cool for 2 min.

4 Place the lamp or heat lamp at the end of a table. Remove any reflector or shade from the lamp.

5 Place the collector about 30 cm from the lamp, and turn the collector toward the lamp.

6 Turn on the lamp, and wait 1 min. Then, gradually move the collector toward the lamp in 2 cm increments. Watch the temperature carefully. At each position, let the collector sit until the temperature reading stabilizes. Stop moving the collector when the temperature reaches the maximum temperature that was achieved in sunlight.

7 Once the temperature has stabilized at the same level reached in sunlight, record the distance between the center of the lamp and the thermometer bulb.

Step 6

ANALYSIS AND CONCLUSION

1 **Analyzing Results** Because the collector reached the same temperature in both trials, the collector absorbed as much energy from the sun at a distance of 150 million km as it did from the light bulb at the distance that you measured. Using 1.5×10^{13} cm as the distance to the sun, calculate the power of the sun in watts by using the equation that follows. The power of the lamp is equal to the wattage of the light bulb.

$$\frac{power_{sun}}{(distance_{sun})^2} = \frac{power_{lamp}}{(distance_{lamp})^2}$$

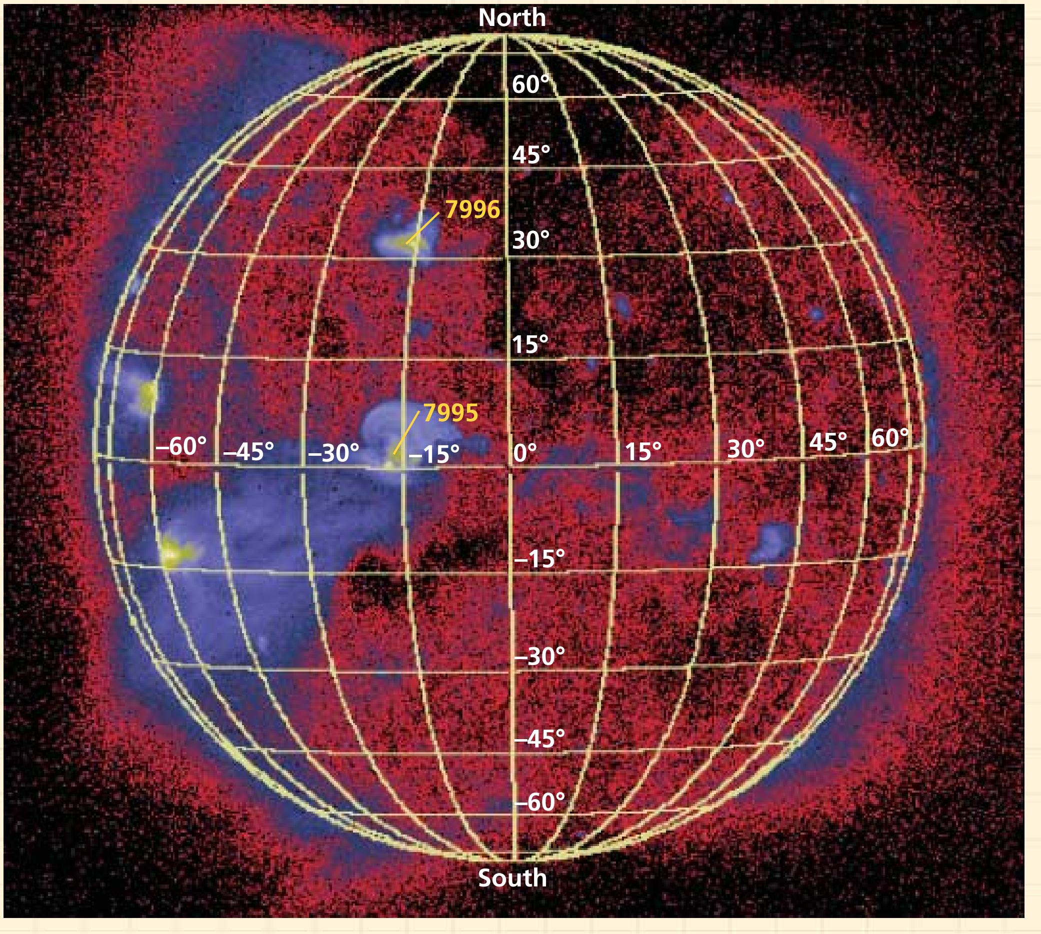
2 **Evaluating Models** The sun's power is generally given as 3.7×10^{26} W. Calculate your experimental percentage error by first subtracting your experimental value from the accepted value. Divide this difference by the accepted value, and multiply by 100. Describe two possible sources for your calculated error.

Extension

1 **Evaluating Models** How would using a fluorescent bulb instead of an incandescent bulb in the experiment affect the results of the experiment? Explain your answer.

MAPS in Action

SXT Composite Image of the Sun

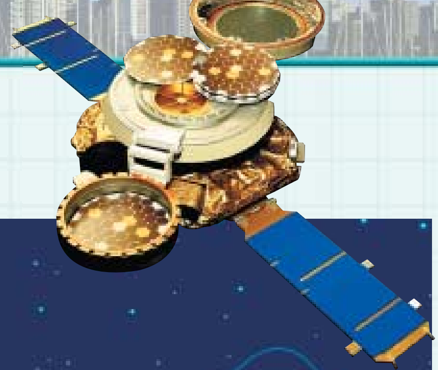


Map Skills Activity

This map is a soft X-ray telescope (SXT) image of the sun that includes latitude and longitude lines. Yellow represents the strongest X-ray radiation. Blue represents moderate X-ray radiation. Red represents the weakest X-ray radiation. The numbered areas are known active regions. Use the map to answer the questions below.

1. **Analyzing Data** Which numbered active region is near the sun's equator?
2. **Analyzing Data** What is the latitude and longitude of the active region numbered 7996?
3. **Inferring Relationships** Why do the lines of solar longitude appear to be close to each other near the left side and the right side of the map?
4. **Interpreting Data** Coronal holes produce almost no X-ray radiation, so they appear as black regions on the map. What is the range of longitudes covered by the coronal hole in the southwestern quadrant of the map?
5. **Analyzing Relationships** Sunspots emit large amounts of X-ray radiation. Where on this map would you expect to find sunspots?

The Genesis Mission

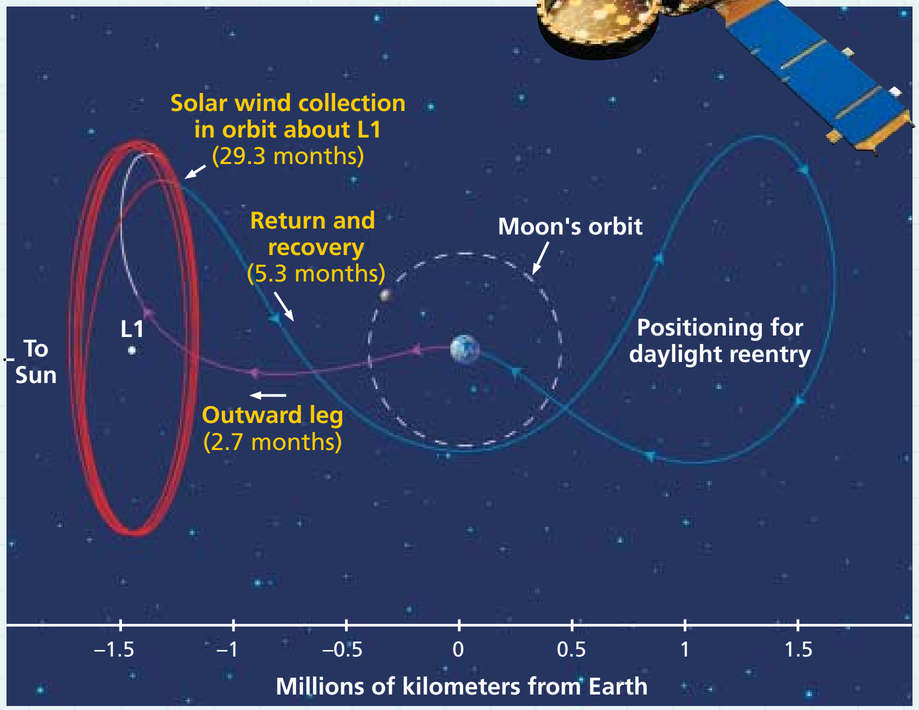


What makes up the sun? Are the materials that make up Earth the same as those that make up other planets? These are only a few of the questions that NASA hoped an ambitious project called *The Genesis Mission* would answer.

Collecting Solar Wind

The Genesis mission began on August 8, 2001, when NASA launched its *Genesis* spacecraft. The spacecraft traveled 1.5 million kilometers toward the sun to an area called *Lagrange Point 1* (L1). L1 is a point in space outside Earth's magnetic field where the gravitational pulls of Earth and the sun are balanced.

Once at L1, the *Genesis* spacecraft collected electrically charged particles called *ions,* which make up solar wind. The spacecraft's solar collector contained pure materials that trapped the solar ions that collided with the collector. Another device, called the *concentrator,* consolidated the ions. The spacecraft's solar wind monitors collected data and helped coordinate the motions of the solar collectors and the concentrator. On April 1, 2004, after two years of collecting particles, the collectors were shut down in preparation for their scheduled September 8, 2004, return to Earth.



▶ The *Genesis* spacecraft collected solar wind particles.

Bringing the Sun to Earth

During the return to Earth, Genesis's parachute failed to open and the space capsule crashed into the Utah desert at nearly 200 mi/h. Scientists transported the damaged canister containing the collectors to a specially built clean room. Clean rooms are rooms in which specialized air filters and flooring reduce the number of airborne particles that may contaminate the samples.

Despite the crash, scientists remain hopeful that the samples recovered from the canister will provide enough data to help them measure the composition of the solar wind. The composition of the solar wind can be used to indirectly measure the abundance of isotopes and elements in the sun. Scientists hope to compare isotope data with data collected from comets, asteroids, and other bodies that formed at the beginning of our solar system.

Extension

1. **Evaluating Conclusions** Research the results of the scientists' investigation of Genesis's canister.

Chapter 30 Stars, Galaxies, and the Universe

Sections

What You'll Learn

- How stars are organized by their characteristics
- How stars form and die
- How stars are grouped into clusters and galaxies
- What the universe is like and how it formed

Why It's Relevant

Our solar system is only one small part of the universe. By studying stars and galaxies, we can learn more about the formation and evolution of our universe.

PRE-READING ACTIVITY

FOLDNOTES

Layered Book Before you read this chapter, create the **FoldNote** entitled "Layered Book" described in the Skills Handbook section of the Appendix. Label the tabs of the layered book with "Star types," "Stellar evolution," "Star groups," and "Origin of the universe." As you read the chapter, write information you learn about each category under the appropriate tab.

▶ New stars are currently forming in the Tarantula nebula, an enormous region of dust and ionized gas.

Section 1 Characteristics of Stars

A **star** is a ball of gases that gives off a tremendous amount of electromagnetic energy. This energy comes from nuclear fusion within the star. *Nuclear fusion* is the combination of light atomic nuclei to form heavier atomic nuclei.

As seen from Earth, most stars in the night sky appear to be tiny specks of white light. However, if you look closely at the stars, you will notice that they vary in color. For example, the star Antares shines with a slightly reddish color, the star Rigel shines blue-white, and the star Arcturus shines with an orange tint. Our own star, Sol, is a yellow star.

OBJECTIVES

- **Describe** how astronomers determine the composition and temperature of stars.
- **Explain** why stars appear to move in the sky.
- **Describe** one way astronomers measure the distances to stars.
- **Explain** the difference between absolute magnitude and apparent magnitude.

KEY TERMS

star
Doppler effect
light-year
parallax
apparent magnitude
absolute magnitude

Analyzing Starlight

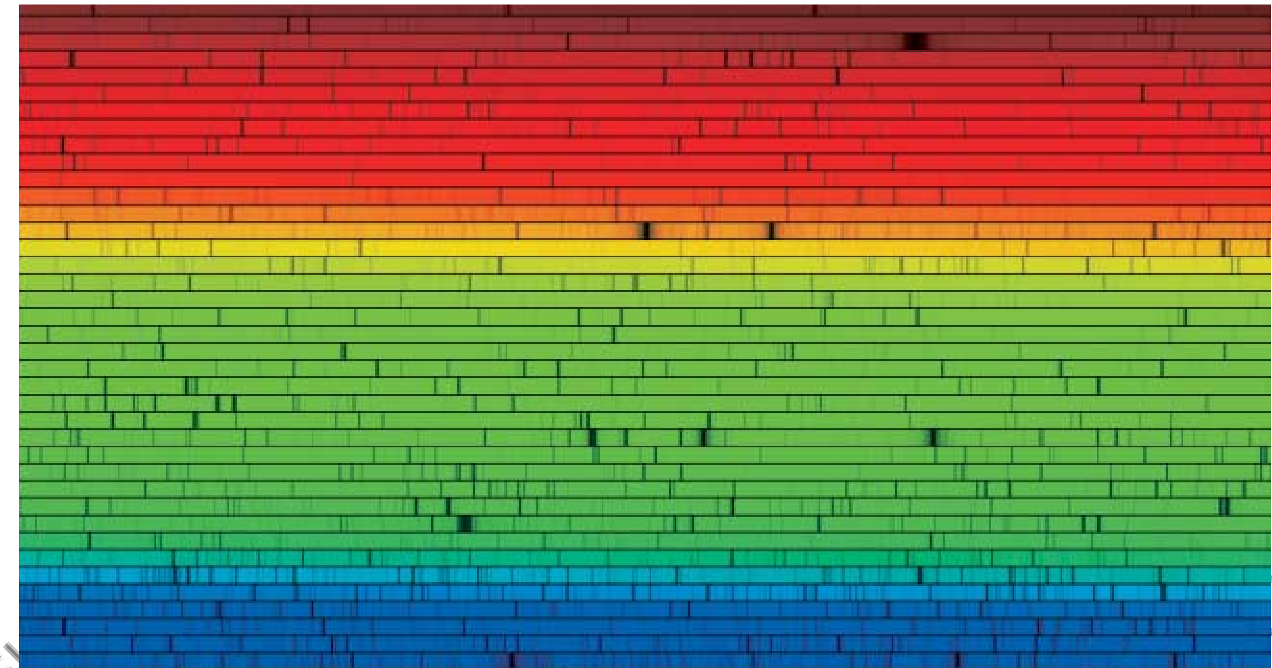
Astronomers learn about stars primarily by analyzing the light that the stars emit. Astronomers direct starlight through *spectrographs,* which are devices that separate light into different colors, or wavelengths. Starlight passing through a spectrograph produces a display of colors and lines called a *spectrum.* There are three types of spectra: *emission,* or bright-line; *absorption,* or dark-line; and *continuous*.

All stars have *dark-line spectra*—bands of color crossed by dark lines where the color is diminished, as shown in **Figure 1.** A star's dark-line spectrum reveals the star's composition and temperature.

Stars are made up of different elements in the form of gases. While the inner layers of a star are very hot, the outer layers are somewhat cooler. Elements in the outer layers absorb some of the light radiating from within the star. Because different elements absorb different wavelengths of light, scientists can determine the elements that make up a star by studying its spectrum.

star a large celestial body that is composed of gas and that emits light

Figure 1 ▶ The spectrum of the sun consists of bands of color crossed by dark absorption lines. This spectrum has been cut into strips that have been arranged vertically.



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Classification of Stars

Color	Surface temperature (°C)	Examples
Blue	above 30,000	10 Lacertae
Blue-white	10,000–30,000	Rigel, Spica
White	7,500–10,000	Vega, Sirius
Yellow-white	6,000–7,500	Canopus, Procyon
Yellow	5,000–6,000	sun, Capella
Orange	3,500–5,000	Arcturus, Aldebaran
Red	less than 3,500	Betelgeuse, Antares

Figure 2 ▶ Stars in the sky show tinges of different colors, which reveal the stars' temperatures. Blue stars shine with the hottest temperatures, and red stars shine with the coolest.

The Compositions of Stars

Every chemical element has a characteristic spectrum in a given range of temperatures. The colors and lines in the spectrum of a star indicate the elements that make up the star. Through spectrum analysis, scientists have learned that stars are made up of the same elements that compose Earth. But while the most common element on Earth is oxygen, the most common element in stars is hydrogen. Helium is the second most common element in stars. Elements such as carbon, oxygen, and nitrogen, usually in small quantities, make up most of the remaining mass of stars.

The Temperatures of Stars

The surface temperature of a star is indicated by the star's color, as shown in **Figure 2.** The temperature of most stars ranges from 2,800°C to 24,000°C, although a few stars are hotter. Generally, a star that shines with blue light has an average surface temperature of 35,000°C. However, the surface temperatures of some blue stars are as high as 50,000°C. Red stars are the coolest stars and have average surface temperatures of 3,000°C. Yellow stars, such as the sun, have surface temperatures of about 5,500°C.

The Sizes and Masses of Stars

Stars also vary in size and mass. Some dwarf stars are about the same size as Earth. The sun, a medium-sized star, has a diameter of about 1,390,000 km. Some giant stars have diameters that are 1,000 times the sun's diameter. Most stars visible from Earth are medium-sized stars that are similar to our sun.

Many stars also have about the same mass as the sun, though some stars may be significantly more or less massive. Stars that are very dense may have more mass than the sun and still be much smaller than the sun. Less-dense stars may have a larger diameter than the sun has but still have less mass than the sun.

Stellar Motion

Two kinds of motion are associated with stars—actual motion and apparent motion. Because stars are so far from Earth, their actual motion can be measured only with high-powered telescopes and other specialized instruments. Apparent motion, on the other hand, is much more noticeable.

Apparent Motion of Stars

The *apparent motion* of stars, or motion visible to the unaided eye, is caused by the movement of Earth. By aiming a camera at the sky and leaving the shutter open for a few hours, you can photograph the apparent motion of the stars. The curves of light in **Figure 3** record the apparent motion of stars in the northern sky. The circular trails make it seem as though the stars are moving counter-clockwise around a central star called Polaris, or the North Star. The circular pattern is caused by the rotation of Earth on its axis. Polaris is almost directly above the North Pole, and thus the star does not appear to move much.

Earth's revolution around the sun causes the stars to appear to move in a second way. Stars located on the side of the sun opposite Earth are obscured by the sun. As Earth orbits the sun, however, different stars become visible during different seasons. The visible stars appear to shift slightly to the west every night. Each night, most stars appear a small distance farther across the sky than they were the night before. After many months, they may finally disappear below the western horizon.

Reading Check **Why does Polaris appear to remain stationary in the night sky? (See the Appendix for answers to Reading Checks.)**

SCILINKS. NSTA Developed and maintained by the National Science Teachers Association

For a variety of links related to this subject, go to www.scilinks.org

Topic: Stars

SciLinksCode: HQ61448

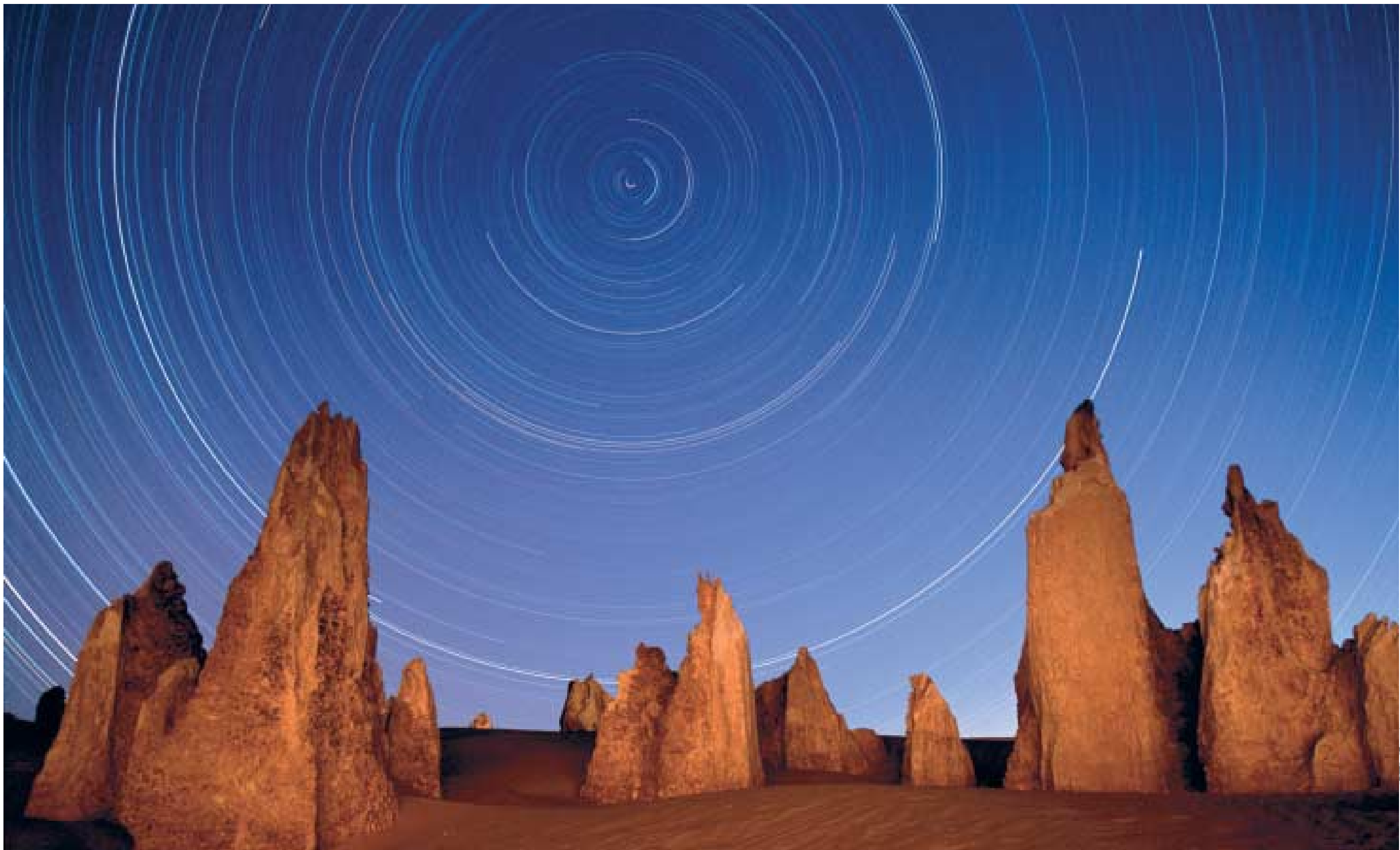

Figure 3 ▶ Stars appear as curved trails in this long-exposure photograph. These trails result from the rotation of Earth on its axis.

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Circumpolar Stars

Some stars are always visible in the night sky. These stars never pass below the horizon in either their nightly or annual movements. In the Northern Hemisphere, the movement of these stars makes them appear to circle Polaris, the North Star. These circling stars are called *circumpolar stars*. The stars of the Little Dipper are circumpolar for most observers in the Northern Hemisphere. At the North Pole, all visible stars are circumpolar. The farther the observer moves from the North Pole toward the equator, the fewer circumpolar stars the observer will be able to see.

Actual Motion of Stars

Most stars have several types of *actual motion*. First, they rotate on an axis. Second, they may revolve around another star. Third, they either move away from or toward our solar system.

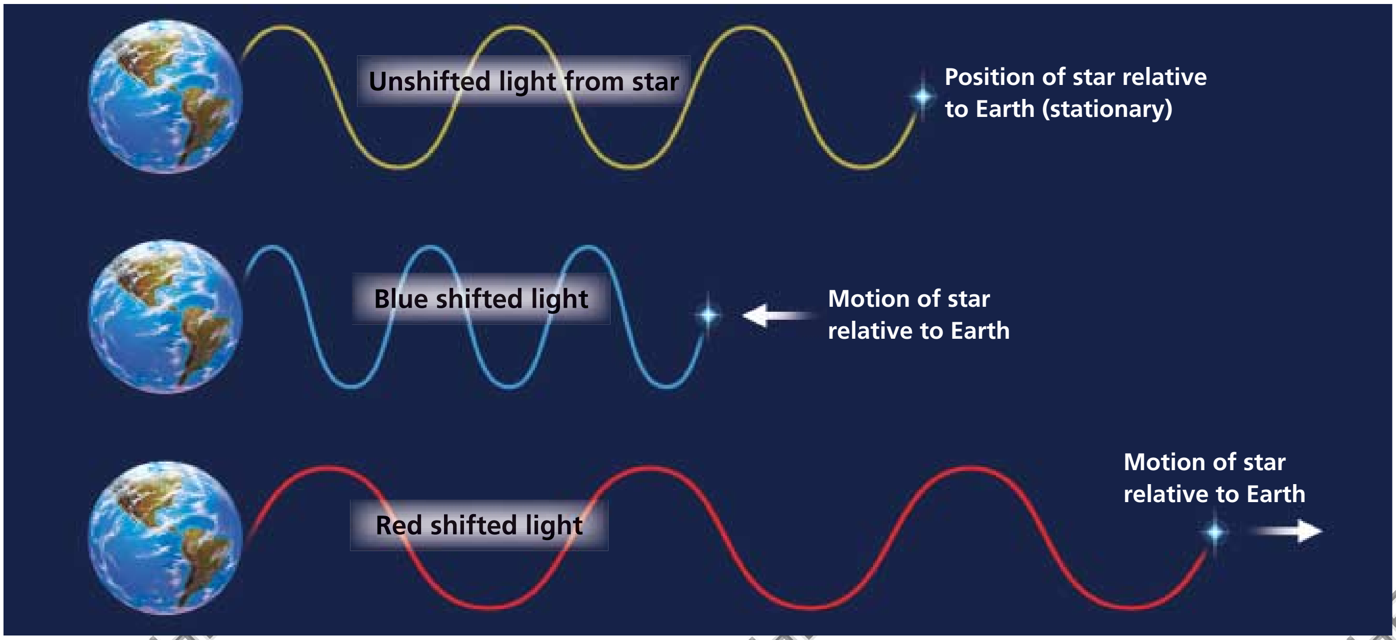
From a star's spectrum, astronomers can learn more about how that star is moving in space. The spectrum of a star that is moving toward or away from Earth appears to shift, as shown in **Figure 4.** The apparent shift in the wavelength of light emitted by a light source moving toward or away from an observer is called the **Doppler effect.** The colors in the spectrum of a star moving toward Earth are shifted slightly toward blue. This shift, called *blue shift,* occurs because the light waves from a star appear to have shorter wavelengths as the star moves toward Earth.

A star moving away from Earth has a spectrum that is shifted slightly toward red. This shift, called *red shift,* occurs because the wavelengths of light appear to be longer. Most distant galaxies, or large groups of stars, have red-shifted spectra, which indicate that these galaxies or stars are moving away from Earth.

Reading Check **What causes starlight to shift toward the red end of the spectrum? (See the Appendix for answers to Reading Checks.)**

Doppler effect an observed change in the frequency of a wave when the source or observer is moving

Figure 4 ▶ The light from stars is shifted based on the star's movement in relationship to Earth. For example, light from stars that are moving away from Earth is shifted slightly toward the red end of the spectrum.



Distances to Stars

Because space is so vast, distances between the stars and Earth are measured in light-years. A **light-year** is the distance that light travels in one year. Because the speed of light is 300,000 km/s, light travels about 9.46 trillion km in one year. The light you see when you look at a star left that star sometime in the past. Light from the sun, for example, takes about 8 minutes to reach Earth. The sun is therefore 8 light-minutes from Earth. When we witness an event on the sun, such as a solar flare, the event actually took place about 8 minutes before we saw it.

Apart from the sun, the star nearest Earth is Proxima Centauri. This star is 4.2 light-years from Earth, nearly 300,000 times the distance from Earth to the sun. Polaris is 700 light-years from Earth. When you look at Polaris, you see the star the way it was 700 years ago.

For relatively close stars, scientists can determine a star's distance by measuring **parallax,** the apparent shift in a star's position when viewed from different locations. As Earth orbits the sun, observers can study the stars from different perspectives, as shown in **Figure 5.** As Earth moves halfway around its orbit, a nearby star will appear to shift slightly relative to stars that are farther from Earth. The closer the star is to Earth, the larger the shift will be. Using this method, astronomers can calculate the distance to any star within 1,000 light-years of Earth.

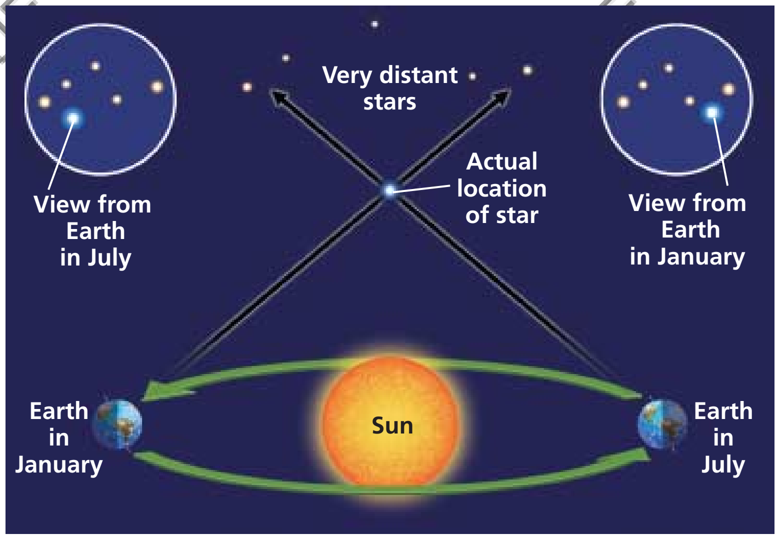


Figure 5 ▶ Observers on Earth see nearby stars against those in the distant background. The movement of Earth causes nearby stars to appear to move back and forth each year.

light-year the distance that light travels in one year

parallax an apparent shift in the position of an object when viewed from different locations

QuickLAB 15 min

Parallax

Procedure

1. Use a **metric ruler** and **scissors** to cut **five 1 m lengths of thread.** Use **masking tape** to tape one end of each piece of thread to the edge of a **paper plate.** Each plate should have the same diameter. One plate should be red, and four should be blue.
2. Stand on a **ladder,** and tape the free end of each piece of thread to the ceiling at various heights. Place the thread 30 cm apart in a staggered pattern. Hang the plates in a location that allows the widest field of view and movement.
3. Stand directly in front of and facing the red plate at a distance of several meters.
4. Close one eye, and sketch the position of the red plate in relation to the blue plates.
5. Take several steps back and to the right. Repeat step 4.
6. Take several more steps and make another sketch.
7. Repeat step 6.

Analysis

1. Compare your drawings. Did the red plate change position as you viewed it from different locations? Explain your answer.
2. What results would you expect if you continued to repeat step 6? Explain your answer.
3. If you noted the positions of several stars by using a powerful telescope, what would you expect to observe about their positions if you saw the same stars six months later? Explain.

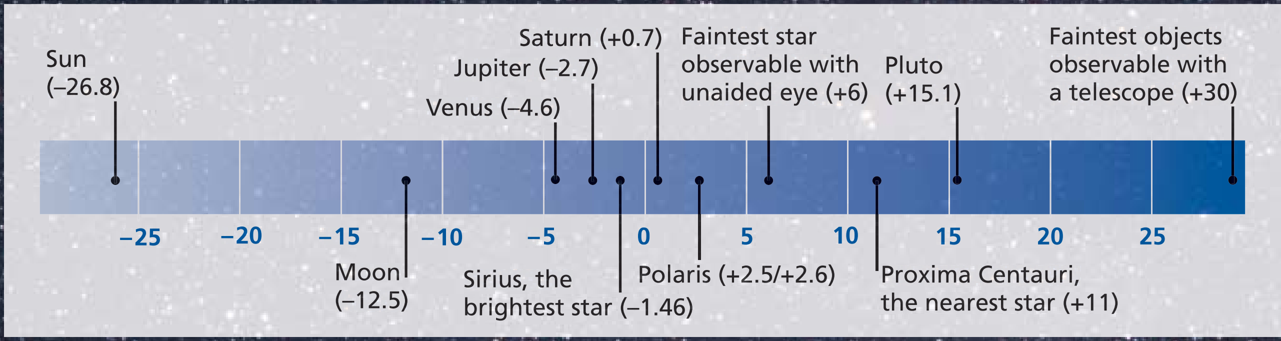


Figure 6 ▶ The sun, which has an apparent magnitude of –26.8, is the brightest object in our sky. All other objects appear dimmer in the sky, so their apparent magnitudes are higher on the scale.

Stellar Brightness

More than 3 billion stars can be seen through telescopes on Earth. Of these, only about 6,000 are visible without a telescope. Billions more stars can be observed from Earth-orbiting telescopes, such as the *Hubble Space Telescope*. The visibility of a star depends on its brightness and its distance from Earth. Astronomers use two scales to describe the brightness of a star.

The brightness of a star as it appears to us on Earth is called the star's **apparent magnitude.** The apparent magnitude of a star depends on both how much light the star emits and how far the star is from Earth. The lower the number of the star on the scale shown in **Figure 6,** the brighter the star appears to observers on Earth. The true brightness, or **absolute magnitude,** of a star is how bright the star would appear if all the stars were at a standard, uniform distance from Earth. The brighter a star actually is, the lower the number of its absolute magnitude.

apparent magnitude the brightness of a star as seen from the Earth

absolute magnitude the brightness that a star would have at a distance of 32.6 light-years from Earth

Section 1 Review

1. **Describe** what astronomers analyze to determine the composition and surface temperature of a star.
2. **Compare** the mass of the sun with the masses of most other stars in the universe.
3. **Explain** why, as you observe the night sky over time, stars appear to move westward across the sky.
4. **Describe** the units used to measure the distance to stars in terms of whether their starlight takes minutes or years to reach Earth.
5. **Describe** the method astronomers use to measure the distance to stars that are less than 1,000 light-years from Earth.
6. **Explain** the difference between apparent magnitude and absolute magnitude.

CRITICAL THINKING

7. **Identifying Relationships** How does the movement of Earth affect the apparent movement of stars in the sky?
8. **Analyzing Ideas** Why is it better for astronomers to measure parallax by observing every six months instead of observing every year?
9. **Understanding Relationships** If two stars have the same absolute magnitude, but one of the stars is farther from Earth than the other one, which star would appear brighter in the night sky?

CONCEPT MAPPING

10. Use the following terms to create a concept map: *star, apparent magnitude, red shift, Doppler effect, light-year, absolute magnitude,* and *blue shift.*

Section 2 Stellar Evolution

Because a typical star exists for billions of years, astronomers will never be able to observe one star throughout its entire lifetime. Instead, they have developed theories about the evolution of stars by studying stars in different stages of development.

OBJECTIVES

- **Describe** how a protostar becomes a star.
- **Explain** how a main-sequence star generates energy.
- **Describe** the evolution of a star after its main-sequence stage.

KEY TERMS

main sequence
nebula
giant
white dwarf
nova
neutron star
pulsar
black hole

Classifying Stars

Plotting the surface temperatures of stars against their *luminosity,* or the total amount of energy they give off each second, reveals a consistent pattern. The graph that illustrates this pattern is the *Hertzsprung-Russell diagram,* or *H-R diagram,* a simplified version of which is shown in **Figure 1.** The graph is named for Ejnar Hertzsprung and Henry Norris Russell, the astronomers who discovered the pattern nearly 100 years ago. The temperature of a star's surface is plotted on the horizontal axis. The luminosity of a star is plotted on the vertical axis.

Astronomers use the H-R diagram to describe the life cycles of stars. Astronomers always plot the highest temperatures on the left and the highest luminosities at the top. The temperature and luminosity for most stars falls within a band that runs diagonally through the middle of the H-R diagram. This band, which extends from cool, dim, red stars at the lower right to hot, bright, blue stars at the upper left, is known as the **main sequence.** Stars within this band are called *main-sequence stars.* The sun is one example of a main-sequence star.

main sequence the location on the H-R diagram where most stars lie; it has a diagonal pattern from the lower right to the upper left

Figure 1 ▶ The Hertzsprung-Russell Diagram

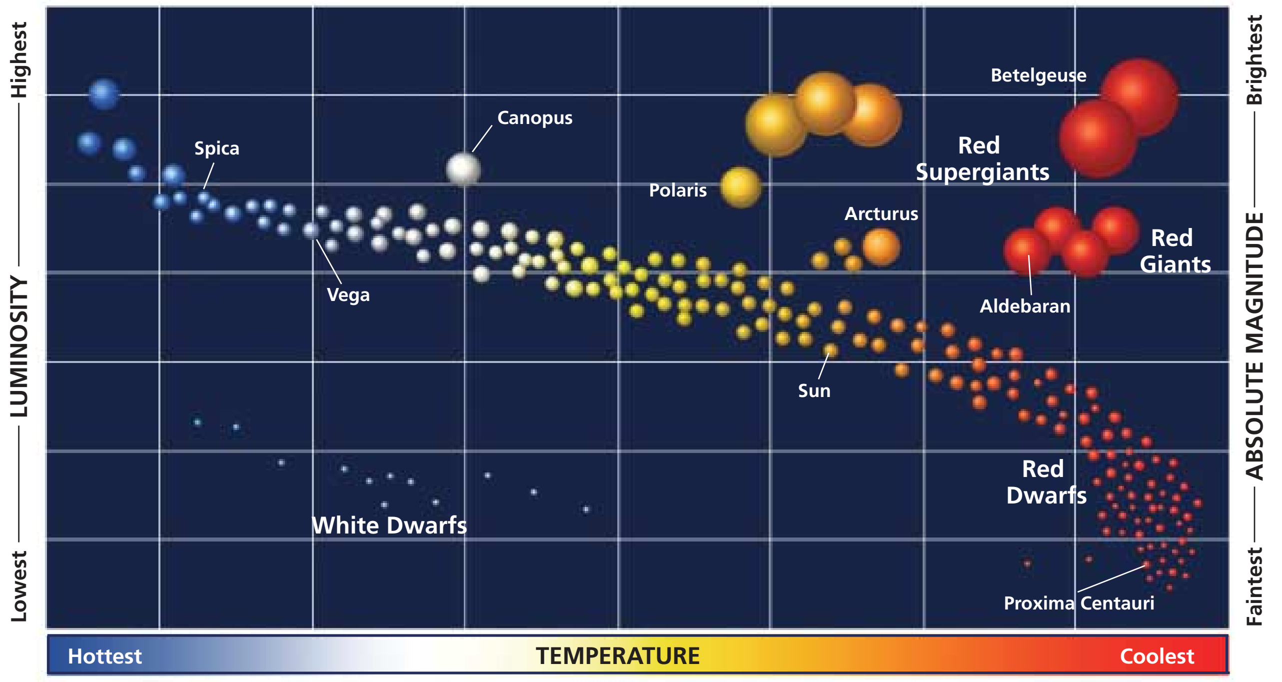


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Figure 2 ▶ The Eagle Nebula is a region in which star formation is currently taking place. This false-color image was captured by the *Hubble Space Telescope*.

Star Formation

nebula a large cloud of gas and dust in interstellar space; a region in space where stars are born

A star begins in a **nebula** (NEB yu luh), a cloud of gas and dust, such as the one shown in **Figure 2.** A nebula commonly consists of about 70% hydrogen, 28% helium, and 2% heavier elements. When an outside force, such as the explosion of a nearby star compresses the cloud, some of the particles move close to each other and are pulled together by gravity.

According to Newton's *law of universal gravitation,* all objects in the universe attract each other through gravitational force. This gravitational force increases as the mass of an object increases or as the distance between two objects decreases. Therefore, as gravity pulls particles closer together, the gravitational pull of the particles on each other increases. This increase in gravitational force causes more nearby particles to be pulled toward the area of increasing mass. As more particles come together, regions of dense matter begin to build up within the cloud.

Protostars

As gravity makes these dense regions more compact, any spin the region has is greatly amplified. The shrinking, spinning region begins to flatten into a disk that has a central concentration of matter called a *protostar*. Gravitational energy is converted into heat energy as more matter is pulled into the protostar. This heat energy causes the temperature of the protostar to increase.

The protostar continues to contract and increase in temperature for several million years. Eventually, the gas becomes so hot that its electrons are stripped from their parent atoms. The nuclei and free electrons move independently, and the gas is then considered a separate state of matter called plasma. *Plasma* is a hot, ionized gas that consists of an equal number of free-moving positive ions and electrons.

MATHPRACTICE

Nuclear Fusion

The sun converts nearly 545 million metric tons of hydrogen to helium every second. In the process, approximately 3.6 million metric tons of that hydrogen mass is changed into energy and radiated into space. What percentage of the converted hydrogen is changed into radiated energy? If the sun loses 3.6 million metric tons of mass per second, how many metric tons of mass will it lose in one year?

The Birth of a Star

Temperature continues to increase in a protostar to about 10,000,000°C. At this temperature, nuclear fusion begins. *Nuclear fusion* is a process that occurs when extremely high temperature and pressure cause less-massive atomic nuclei to combine to form more-massive nuclei and, in the process, release enormous amounts of energy. The onset of fusion marks the birth of a star. Once nuclear fusion begins in a star, the process can continue for billions of years.

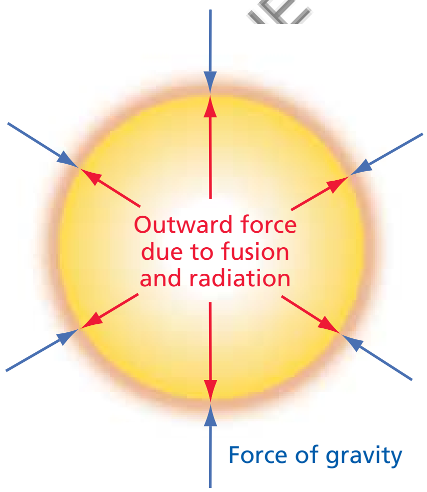


Figure 3 ▶ Stellar equilibrium is achieved when the inward force of gravity is balanced by the outward pressure from fusion and radiation inside the star.

A Delicate Balancing Act

As gravity increases the pressure on the matter within the star, the rate of fusion increases. In turn, the energy radiated from fusion reactions heats the gas inside the star. The outward pressures of the radiation and the hot gas resist the inward pull of gravity. The stabilizing effect of these forces is shown in **Figure 3.** This equilibrium makes the star stable in size. A main-sequence star maintains a stable size as long as the star has an ample supply of hydrogen to fuse into helium.

Reading Check **How does the pressure from fusion and hot gas interact with the force of gravity to maintain a star's stability? (See the Appendix for answers to Reading Checks.)**

The Main-Sequence Stage

The second and longest stage in the life of a star is the main-sequence stage. During this stage, energy continues to be generated in the core of the star as hydrogen fuses into helium. Fusion releases enormous amounts of energy. For example, when only 1 g of hydrogen is converted into helium, the energy released could keep a 100 W light bulb burning for more than 200 years.

A star that has a mass about the same as the sun's mass stays on the main sequence for about 10 billion years. More-massive stars, on the other hand, fuse hydrogen so rapidly that they may stay on the main sequence for only 10 million years. Because the universe is about 14 billion years old, massive stars that formed long ago have long since left the main sequence. Less massive stars, which are at the bottom right of the main sequence on the H-R diagram, are thought to be able to exist for hundreds of billions of years.

The stages in the life of a star cover an enormous period of time. Scientists estimate that over a period of almost 5 billion years, the sun, shown in **Figure 4,** has converted only 5% of its original hydrogen nuclei into helium nuclei. After another 5 billion years, though, with 10% of the sun's original hydrogen converted, fusion will stop in the core. When fusion stops, the sun's temperature and luminosity will change and the sun will move off the main sequence.

Figure 4 ▶ Our sun is a yellow star. It is located in the diagonal band of main-sequence stars on the H-R diagram.

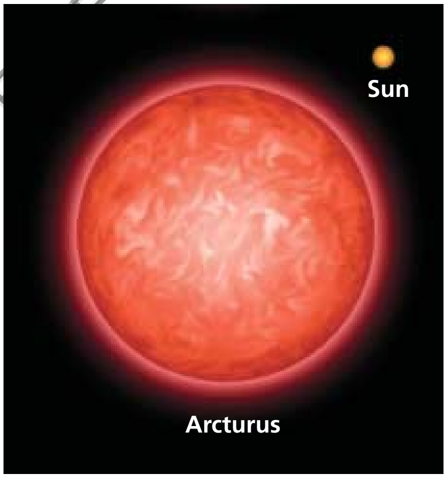


Figure 5 ▶ Arcturus is an orange giant that is about 23 times larger than the sun. Despite being about 1,000°C cooler than the sun, Arcturus gives off more than 100 times as much light as the sun does.

giant a very large and bright star whose hot core has used most of its hydrogen

Leaving the Main Sequence

A star enters its third stage when almost all of the hydrogen atoms within its core have fused into helium atoms. Without hydrogen for fuel, the core of a star contracts under the force of its own gravity. This contraction increases the temperature in the core. As the helium core becomes hotter, it transfers energy into a thin shell of hydrogen surrounding the core. This energy causes hydrogen fusion to continue in the shell of gas. The on-going fusion of hydrogen radiates energy outward, which causes the outer shell of the star to expand greatly.

Giant Stars

A star's shell of gases grows cooler as it expands. As the gases in the outer shell become cooler, they begin to glow with a reddish color. These large, red stars are known as **giants.**

Because of their large surface areas, giant stars are bright. Giants, such as the star Arcturus shown in **Figure 5,** are 10 or more times larger than the sun. Stars that contain about as much mass as the sun will become giants. As they become larger, more luminous, and cooler, they move off the main sequence. Giant stars are above the main sequence on the H-R diagram.

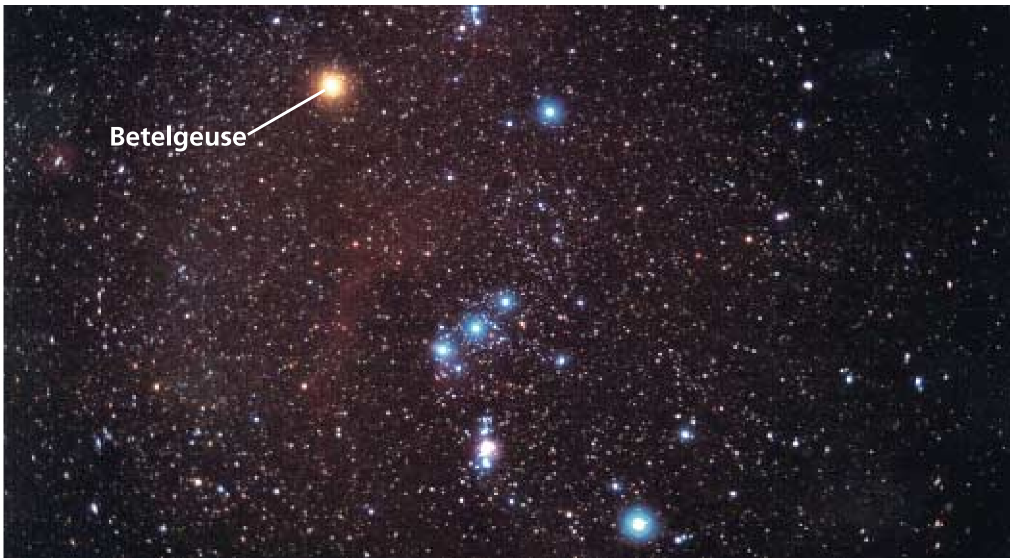
Supergiants

Main-sequence stars that are more massive than the sun will become larger than giants in their third stage. These highly luminous stars are called *supergiants*. These stars appear along the top of the H-R diagram. Supergiants are often at least 100 times larger than the sun. Betelgeuse, the large, orange-red star shown in **Figure 6,** is one example of a supergiant. Located in the constellation Orion, Betelgeuse is 1,000 times larger than the sun.

Though such supergiant stars make up only a small fraction of all the stars in the sky, their high luminosity makes the stars easy to find in a visual scan of the night sky. However, despite the high luminosity of supergiants, their surfaces are relatively cool.

Reading Check **Where are giants and supergiants found on the H-R diagram? (See the Appendix for answers to Reading Checks.)**

Figure 6 ▶ If the sun were replaced by the red supergiant Betelgeuse, the surface of this star would be farther out than Jupiter's orbit. ***How does the temperature of Betelgeuse compare with that of the sun?***



The Final Stages of a Sunlike Star

In the evolution of a medium-sized star, fusion in the core will stop after the helium atoms have fused into carbon and oxygen. With energy no longer available from fusion, the star enters its final stages.

Planetary Nebulas

As the star's outer gases drift away, the remaining core heats these expanding gases. The gases appear as a *planetary nebula,* a cloud of gas that forms around a sunlike star that is dying. Some of these clouds may form a simple sphere or ring around the star. However, many planetary nebulas form more-complex shapes. For example, the Ant nebula has a double-lobed shape, as shown in **Figure 7.**

Figure 7 ▶ The Ant nebula is a planetary nebula that is located more than 3,000 light-years from Earth in the southern constellation Norma.

White Dwarfs

As a planetary nebula disperses, gravity causes the remaining matter in the star to collapse inward. The matter collapses until it cannot be pressed further together. A hot, extremely dense core of matter—a **white dwarf**—is left. White dwarfs shine for billions of years before they cool completely.

White dwarfs are in the lower left of the H-R diagram. They are hot but dim. These stars are very small, about the size of Earth. As white dwarfs cool, they become fainter. This is the final stage in the life cycle of many stars.

When a white dwarf no longer gives off light, the star will become a *black dwarf*. However, this process is long, and many astronomers do not believe that any black dwarf stars yet exist.

white dwarf a small, hot, dim star that is the leftover center of an old star

Connection to TECHNOLOGY

Searching for Extraterrestrial Life

In 1967, scientists discovered strange, regular pulses of radio waves coming from a specific point in space. Some scientists briefly thought these pulses might be coming from an intelligent source and called them LGMs, for *Little Green Men*. Further research showed that the source of these waves was a natural phenomenon, but the idea that there might be life in the universe continued to spur scientific interest.

In 1984, the SETI Institute was founded. The name SETI stands for the Search for Extraterrestrial Intelligence. SETI is dedicated to searching for evidence of extraterrestrial life and signs of alien intelligence.

The SETI program uses telescopes all over Earth to gather data. Many of these telescopes, such as the Arecibo Observatory in Puerto Rico, gather radio data, but optical searches are also performed.

Combing through all the data that the telescopes collect is no small job. In fact, the telescopes often collect more data than SETI's computers can process. In 1998, the SETI@home project was launched by scientists at the University of California at Berkeley. This program allows anyone with a computer and an internet connection to help process the data collected.

nova a star that suddenly becomes brighter

Graphic Organizer **Chain-of-Events Chart**

Create the **Graphic Organizer** entitled "Chain-of-Events Chart" described in the Skills Handbook section of the Appendix. Then, fill in the chart with details about each stage in the life cycle of a main-sequence star.

Novas and Supernovas

Some white dwarf stars are part of a binary star system. If a white dwarf revolves around a red giant, the gravity of the very dense white dwarf may capture gases from the red giant. As these gases accumulate on the surface of the white dwarf, pressure begins to build up. This pressure may cause large explosions, which release energy and stellar material into space, to occur. Such an explosion is called a **nova.**

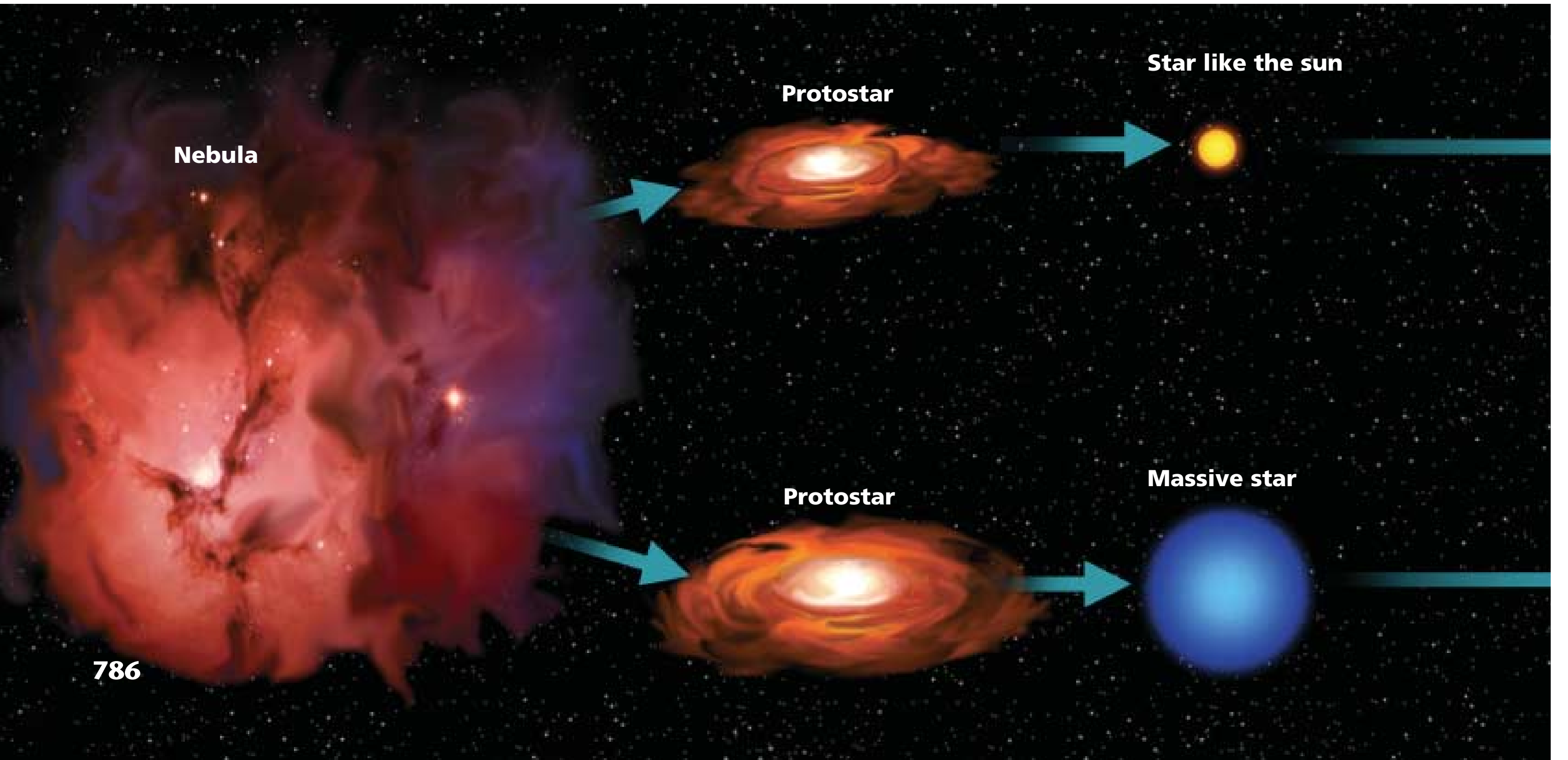
A nova may cause a star to become many thousands of times brighter than it normally is. However, within days, the nova begins to fade to its normal brightness. Because these explosions rarely disrupt the stability of the binary system, the process may start again and a white dwarf may become a nova several times.

A white dwarf star in a binary system may also become a *supernova,* a star that has such a tremendous explosion that it blows itself apart. Unlike an ordinary nova, a white dwarf can sometimes accumulate so much mass on its surface that gravity overwhelms the outward pressure. The star collapses and becomes so dense that the outer layers rebound and explode outward. Supernovas are thousands of times more violent than novas. The explosions of supernovas completely destroy the white dwarf star and may destroy much of the red giant.

The Final Stages of Massive Stars

Stars that have masses of more than 8 times the mass of the sun may produce supernovas without needing a secondary star to fuel them. In 1054, Chinese astronomers saw a supernova so bright that it was seen during the day for more than three weeks. At its peak, the supernova radiated an amount of energy that was equal to the output of about 400 million suns.

Life Cycle of Stars



Supernovas in Massive Stars

While only a small percentage of white dwarfs become supernovas, massive stars become supernovas as part of their life cycle, which is shown in **Figure 8.** After the supergiant stage, these stars contract with a gravitational force that is much greater than that of small-mass stars. The collapse produces such high pressures and temperatures that nuclear fusion begins again. This time, carbon atoms in the core of the star fuse into heavier elements such as oxygen, magnesium, or silicon.

Fusion continues until the core is almost entirely made of iron. Because of the stable nuclear structure of iron, not even the incredible heat and pressure in a star's core can cause it to fuse into heavier elements. Having used up its supply of fuel, the core begins to collapse under its own gravity. Energy released as the core collapses is transferred to the outer layers of the star, which explode outward with tremendous force. Within a few minutes, the energy released by the supernova may surpass the amount of energy radiated by a sunlike star over its entire lifetime.

Reading Check **What causes a supergiant star to explode as a supernova? (See the Appendix for answers to Reading Checks.)**

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For a variety of links related to this subject, go to www.scilinks.org

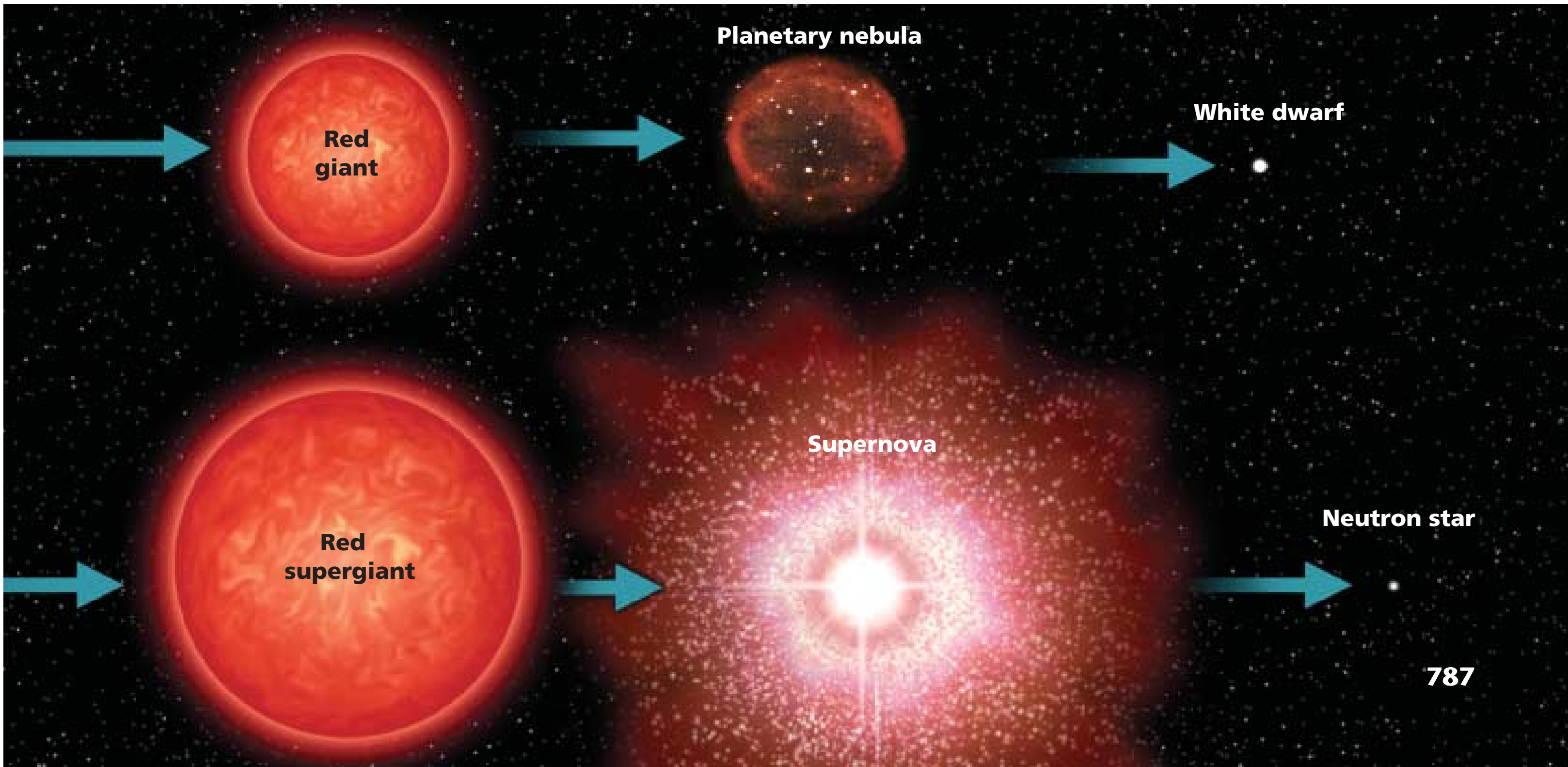
Topic: How Stars Evolve
SciLinksCode: HQ60764

Neutron Stars

Stars that contain about 8 or more times the mass of the sun do not become white dwarfs. After a star explodes as a supernova, the core may contract into a very small but incredibly dense ball of neutrons, called a **neutron star.** A single teaspoon of matter from a neutron star would weigh 100 million metric tons on Earth. A neutron star that has more mass than the sun may have a diameter of only about 20 km but may emit the same amount of energy as 100,000 suns. Neutron stars rotate very rapidly.

neutron star a star that has collapsed under gravity to the point that the electrons and protons have smashed together to form neutrons

Figure 8 ▶ A star the mass of the sun becomes a white dwarf near the end of its life cycle. A more massive star may become a neutron star.



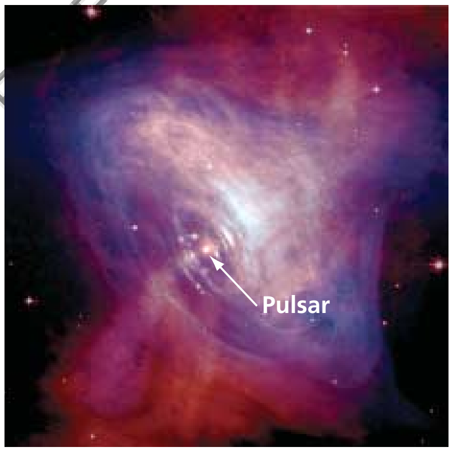


Figure 9 ▶ This pulsar, located in the heart of the Crab nebula, is still surrounded by the remains of a supernova explosion that took place less than 1,000 years ago.

Pulsars

Some neutron stars emit a beam of radio waves that sweeps across space like a lighthouse light beam sweeps across water. Because we detect pulses of radio waves every time the beam sweeps by Earth, these stars are called **pulsars**. For each pulse we detect, we know that the star has rotated within that period. Newly formed pulsars, such as the one shown in **Figure 9**, are commonly surrounded by the remnants of a supernova. But most known pulsars are so old that these remnants have long since dispersed and have left behind only the spinning star.

pulsar a rapidly spinning neutron star that emits pulses of radio and optical energy

black hole an object so massive and dense that even light cannot escape its gravity

Black Holes

Some massive stars produce leftovers too massive to become stable neutron stars. If the remaining core of a star contains more than 3 times the mass of the sun, the star may contract further under its greater gravity. The force of the contraction crushes the dense core of the star and leaves a **black hole**. The gravity of a black hole is so great that nothing, not even light, can escape it.

Because black holes do not give off light, locating them is difficult. But a black hole can be observed by its effect on a companion star. Matter from the companion star is pulled into the black hole. Just before the matter is absorbed, it swirls around the black hole. The gas becomes so hot that X rays are released. Astronomers locate black holes by detecting these X rays. Scientists then try to find the mass of the object that is affecting the companion star. Astronomers conclude that a black hole exists only if the companion star's motion shows that a massive, invisible object is present nearby.

Section 2 Review

1. **Explain** the steps that the gas in a nebula goes through as it becomes a star.
2. **Describe** the process that generates energy in the core of a main-sequence star.
3. **Explain** how a main-sequence star like the sun is able to maintain a stable size.
4. **Describe** how nuclear fusion in a main-sequence star is different from nuclear fusion in a giant star.
5. **Describe** how a star similar to the sun changes after it leaves the main-sequence stage of its life cycle.
6. **Describe** what causes a nova explosion.
7. **Explain** why only very massive stars can form black holes.
8. **Describe** the two types of supernovas.

CRITICAL THINKING

9. **Identifying Relationships** How do astronomers conclude that a supergiant star is larger than a main-sequence star of the same temperature?
10. **Analyzing Ideas** Why would an older main-sequence star be composed of a higher percentage of helium than a young main-sequence star?
11. **Compare and Contrast** Why does temperature increase more rapidly in a more massive protostar than in a less massive protostar?
12. **Analyzing Ideas** How can astronomers detect a black hole if it is invisible to a normal telescope?

CONCEPT MAPPING

13. Use the following terms to create a concept map: *main-sequence star, nebula, supergiant, white dwarf, planetary nebula, black hole, supernova, protostar, giant, pulsar,* and *neutron star.*

Section 3 Star Groups

When you look into the sky on a clear night, you see what appear to be individual stars. These visible stars are only some of the trillions of stars that make up the universe. Most of the ones we see are within 100 light-years of Earth. However, in the constellation Andromeda, there is a hazy region that is actually a huge collection of stars, gas, and dust. This region is more than two million light-years from Earth. It is the farthest one can see with the unaided eye.

OBJECTIVES

- **Describe** the characteristics that identify a constellation.
- **Describe** the three main types of galaxies.
- **Explain** how a quasar differs from a typical galaxy.

KEY TERMS

constellation
galaxy
quasar

Constellations

By using a star chart and observing carefully, you can identify many star groups that form star patterns or regions. Although the stars that make up a pattern appear to be close together, they are not all the same distance from Earth. In fact, they may be very distant from one another, as shown in **Figure 1.**

If you look at the same region of the sky for several nights, the positions of the stars in relation to one another do not appear to change. Because of the tremendous distance from which the stars are viewed, they appear fixed in their patterns. For more than 3,000 years, people have observed and recorded these patterns. These patterns of stars and the region of space around them are called **constellations.**

constellation one of 88 regions into which the sky has been divided in order to describe the locations of celestial objects; a group of stars organized in a recognizable pattern

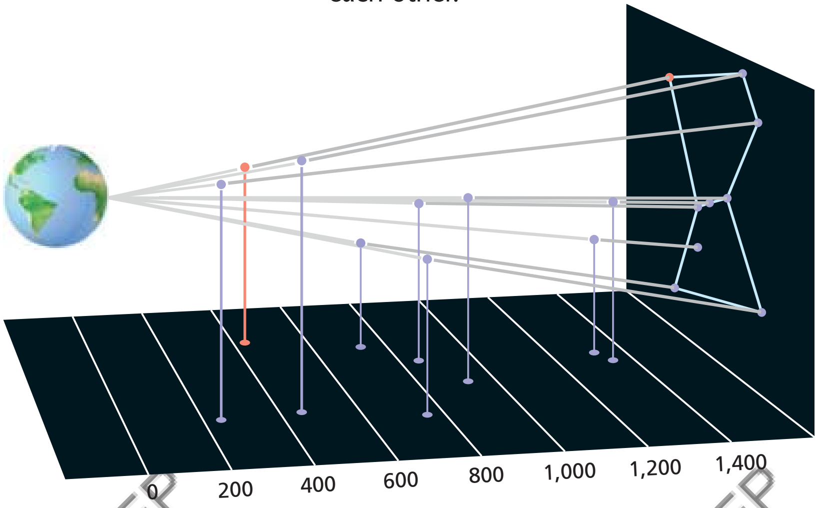
Dividing Up the Sky

In 1930, astronomers around the world agreed upon a standard set of 88 constellations. The stars of these constellations and the regions around them divide the sky into sectors. Just as you can use a road map to locate a particular town, you can use a map of the constellations to locate a particular star. Star charts can be found in the Reference Map section of the Appendix.

Naming Constellations

Many of the modern names we use for the constellations come from Latin. Some constellations are named for real or imaginary animals, such as Ursa Major, which means "the great bear," and Draco, which means "the dragon." Other constellations are named for ancient gods or legendary heroes, such as Hercules and Orion. In some cases, smaller parts of constellations are well known and have their own names. The Big Dipper, for example, is a part of the constellation Ursa Major.

Figure 1 The stars that make up the constellation Orion appear close together when viewed from Earth. However, these stars are located at various distances from Earth and from each other.



Multiple-Star Systems

Stars are not always solitary objects isolated in space. When two or more stars are closely associated, they form multiple-star systems. *Binary stars* are pairs of stars that revolve around each other and are held together by gravity. In systems where the two stars have similar masses, the center of mass, or *barycenter,* will be somewhere between the stars. If one star is more massive than the other, the barycenter will be closer to the more massive star.

Multiple-star systems sometimes have more than two stars. In such a star system, two stars may revolve rapidly around a common barycenter, while a third star revolves more slowly at a greater distance from the pair. Astronomers estimate that more than half of all observed stars are part of multiple-star systems.

galaxy a collection of stars, dust, and gas bound together by gravity

Reading Check **What percentage of stars are in multiple-star systems? (See the Appendix for answers to Reading Checks.)**

Star Clusters

Sometimes, nebulas collapse to form groups of hundreds or thousands of stars, called clusters. *Globular clusters* have a spherical shape and can contain up to 100,000 stars. An *open cluster,* such as the one shown in **Figure 2,** is loosely shaped and rarely contains more than a few hundred stars.

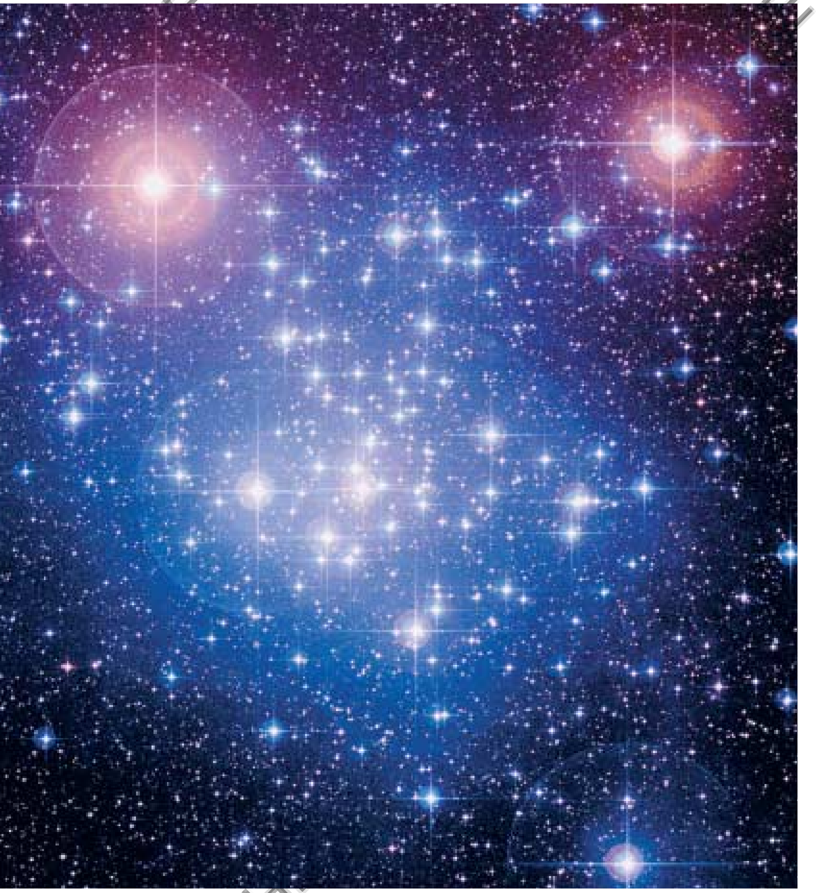


Figure 2 ▶ The open cluster NGC 2516 is made up of about 100 stars. Located about 1,300 light-years from Earth, many of the stars in the cluster appear blue in color.

Galaxies

A large-scale group of stars, gas, and dust that is bound together by gravity is called a **galaxy.** Galaxies are the major building blocks of the universe. A typical galaxy, such as the Milky Way galaxy in which we live, has a diameter of about 100,000 light-years and may contain more than 200 billion stars. Astronomers estimate that the universe contains hundreds of billions of galaxies.

Distances to Galaxies

Some stars allow astronomers to find distances to the galaxies that contain the stars. For example, giant stars called *Cepheid* (SEF ee id) *variables* brighten and fade in a regular pattern. Most Cepheids have regular cycles that range from 1 to 100 days. The longer a Cepheid's cycle is, the brighter the star's visual absolute magnitude is. By comparing the Cepheid's absolute magnitude and the Cepheid's apparent magnitude, astronomers calculate the distance to the Cepheid variable. This distance, in turn, tells them the distance to the galaxy in which the Cepheid is located.

Figure 3 ▶ The three main types of galaxies are spiral (left), elliptical (center), and irregular (right).

Types of Galaxies

In studying galaxies, astronomers found that galaxies could be classified by shape into the three main types shown in **Figure 3.** The most common type, called a *spiral galaxy,* has a nucleus of bright stars and flattened arms that spiral around the nucleus. The spiral arms consist of billions of young stars, gas, and dust. Some spiral galaxies have a straight bar of stars that runs through the center. These galaxies are called *barred spiral galaxies*.

Galaxies of the second type vary in shape from nearly spherical to very elongated, like a stretched-out football. These galaxies are called *elliptical galaxies*. They are extremely bright in the center and do not have spiral arms. Elliptical galaxies have few young stars and contain little dust and gas.

The third type of galaxy, called an *irregular galaxy,* has no particular shape. These galaxies usually have low total masses and are fairly rich in dust and gas. Irregular galaxies make up only a small percentage of the total number of observed galaxies.

The Milky Way

If you look into the night sky, you may see what appears to be a cloudlike band that stretches across the sky. Because of its milky appearance, this part of the sky is called the Milky Way.

The *Milky Way galaxy* is a spiral galaxy in which the sun is one of hundreds of billions of stars. Each star orbits around the center of the Milky Way galaxy. It takes the sun about 225 million years to complete one orbit around the galaxy.

Two irregular galaxies, the Large Magellanic Cloud and Small Magellanic Cloud, are our closest neighbors. Even so, these galaxies are each more than 170,000 light-years away from Earth. Within 5 million light-years of the Milky Way are about 30 other galaxies. These galaxies and the Milky Way galaxy are collectively called the *Local Group*.

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Topic: Galaxies
SciLinksCode: HQ60632
Topic: Milky Way Galaxy
SciLinks code: HQ60964

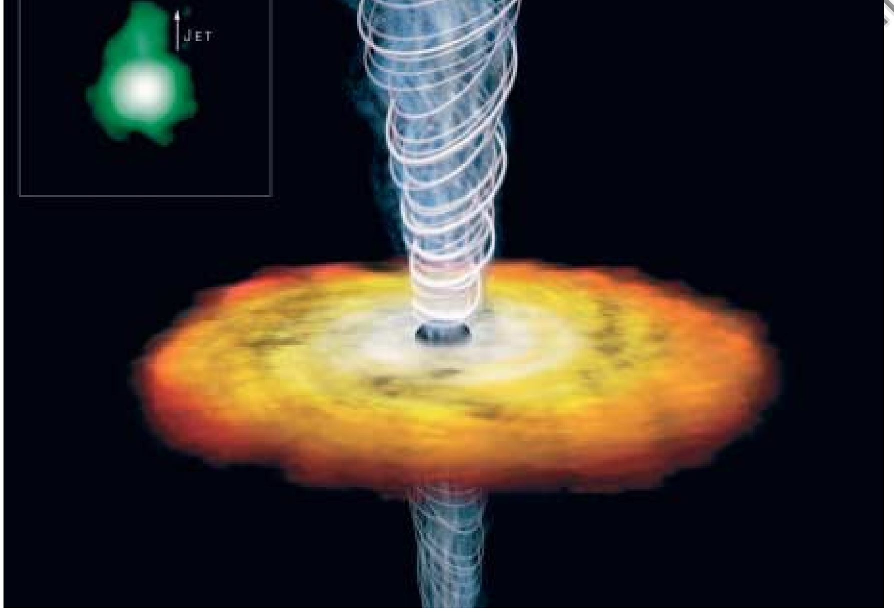


Figure 4 ▶ The jets of gas projected from a quasar can extend for more than 100,000 light-years. Quasars are too distant to be clearly photographed. The image shown is an artist's rendition of a quasar. The smaller inset is an actual image taken by the Chandra X-Ray Observatory.

Quasars

quasar quasi-stellar radio source; a very luminous object that produces energy at a high rate

First discovered in 1963, quasars used to be the most puzzling objects in the sky. Viewed through an optical telescope, a quasar appears as a point of light, almost in the same way that a small, faint star would appear. The word **quasar** is a shortened term for *quasi-stellar radio source*. The prefix *quasi-* means "similar to," and the word *stellar* means "star." Quasars are not related to stars, but quasars are related to galaxies. Some quasars project a jet of gas, as shown in **Figure 4.**

Astronomers have discovered that quasars are located in the centers of galaxies that are distant from Earth. Galaxies that have quasars in them differ from other galaxies in that the quasars in their centers are very bright. The large amount of energy emitted from such a small volume could be explained by the presence of a giant black hole. The mass of such black holes is estimated to be billions of times the mass of our sun. Quasars are among the most distant objects that have been observed from Earth.

Section 3 Review

1. **Identify** the characteristics of a constellation.
2. **List** the three basic types of galaxies.
3. **Describe** the Milky Way galaxy in terms of galaxy types.
4. **Describe** the difference between an typical galaxy and a quasar.

CRITICAL THINKING

5. **Identifying Relationships** Explain how stars can form a constellation when seen from Earth but can still be very far from each other.
6. **Making Calculations** The sun orbits the center of the Milky Way galaxy every 225 million years. How many revolutions has the sun made since the formation of Earth 4.6 billion years ago?
7. **Analyzing Ideas** Why are the constellations that are seen in the winter sky different from those seen in the summer sky?

CONCEPT MAPPING

8. Use the following terms to create a concept map: *galaxy, elliptical galaxy, Milky Way galaxy, irregular galaxy, barred spiral galaxy,* and *spiral galaxy.*

Section 4 The Big Bang Theory

The study of the origin, structure, and future of the universe is called **cosmology.** Cosmologists, or people who study cosmology, are concerned with processes that affect the universe as a whole. Like the parts found within it, the universe is always changing. While some astronomers study how planets, stars, or galaxies form and evolve, a cosmologist studies how the entire universe formed and tries to predict how it will change in the future.

Like all scientific theories, theories about the origin and evolution of the universe must constantly be tested against new observations and experiments. Many current theories of the universe began with observations made less than 100 years ago.

OBJECTIVES

- **Explain** how Hubble's discoveries lead to an understanding that the universe is expanding.
- **Summarize** the big bang theory.
- **List** evidence for the big bang theory.

KEY TERMS

cosmology
big bang theory
cosmic background radiation

Hubble's Observations

Just as the light from a single star can be used to make a stellar spectrum, scientists can also use the light given off by an entire galaxy to create the spectrum for that galaxy. In the early 1900s, finding the spectrum of a galaxy could take the whole night, or even several nights. Although collecting new spectra was very time consuming, the astronomer Edwin Hubble used these galactic spectra to uncover new information about our universe.

cosmology the study of the origin, properties, processes, and evolution of the universe

Measuring Red Shifts

Near the end of the 1920s, Hubble found that the spectra of galaxies, except for the few closest to Earth, were shifted toward the red end of the spectrum. By examining the amount of red shift, he determined the speed at which the galaxies were moving away from Earth. Hubble found that the most distant galaxies showed the greatest red shift and thus were moving away from Earth the fastest.

Many distant galaxies are shown in **Figure 1.** Modern telescopes that have electronic cameras can take images of hundreds of spectra per hour. To date, these spectra all confirm Hubble's original findings.

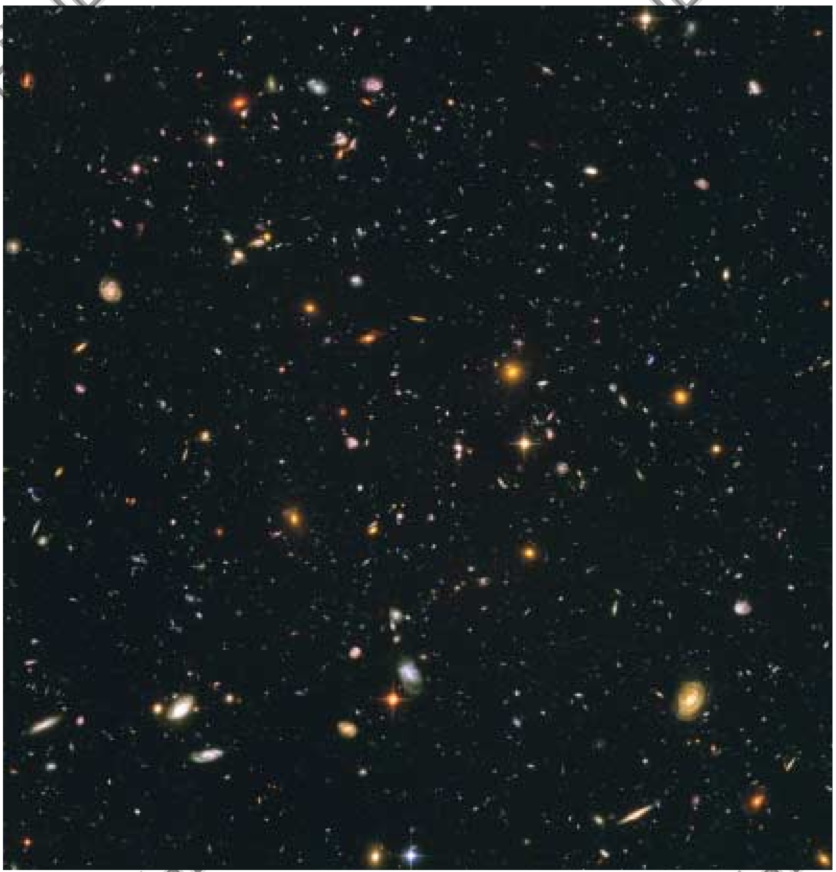


Figure 1 ▶ This image from the *Hubble Space Telescope* shows hundreds of galaxies. These galaxies all have large red shifts, so they are moving away from Earth very fast.

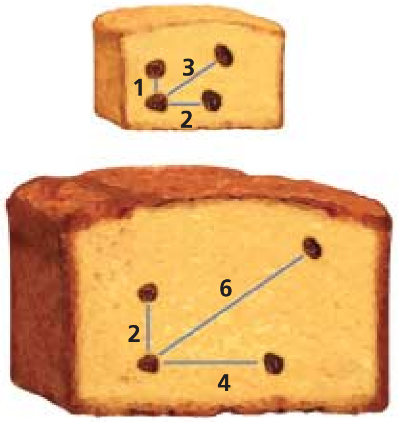


Figure 2 ▶ The farther away one raisin is from another raisin, the faster they move away from each other. Similarly, the farther galaxies are from each other, the faster they move away from each other.

The Expanding Universe

Imagine a raisin cake rising in a kitchen oven. If you were able to sit on one raisin, you would see all the other raisins moving away from you, as shown in **Figure 2.** Raisins that are farther away in the dough when it begins rising move away faster because there is more cake between you and them and because the whole cake is expanding. The situation is similar with galaxies and the universe. By using Hubble's observations, astronomers were able to determine that the universe was expanding.

The Big Bang Theory Emerges

Although cosmologists have proposed several different theories to explain the expansion of the universe, the current and most widely accepted is the big bang theory. The **big bang theory** states that billions of years ago, all the matter and energy in the universe was compressed into an extremely small volume. If you trace the expanding universe back in time, all matter would have been close together at one point in time. About 14 billion years ago, a sudden event called the *big bang* sent all of the matter and energy outward in all directions.

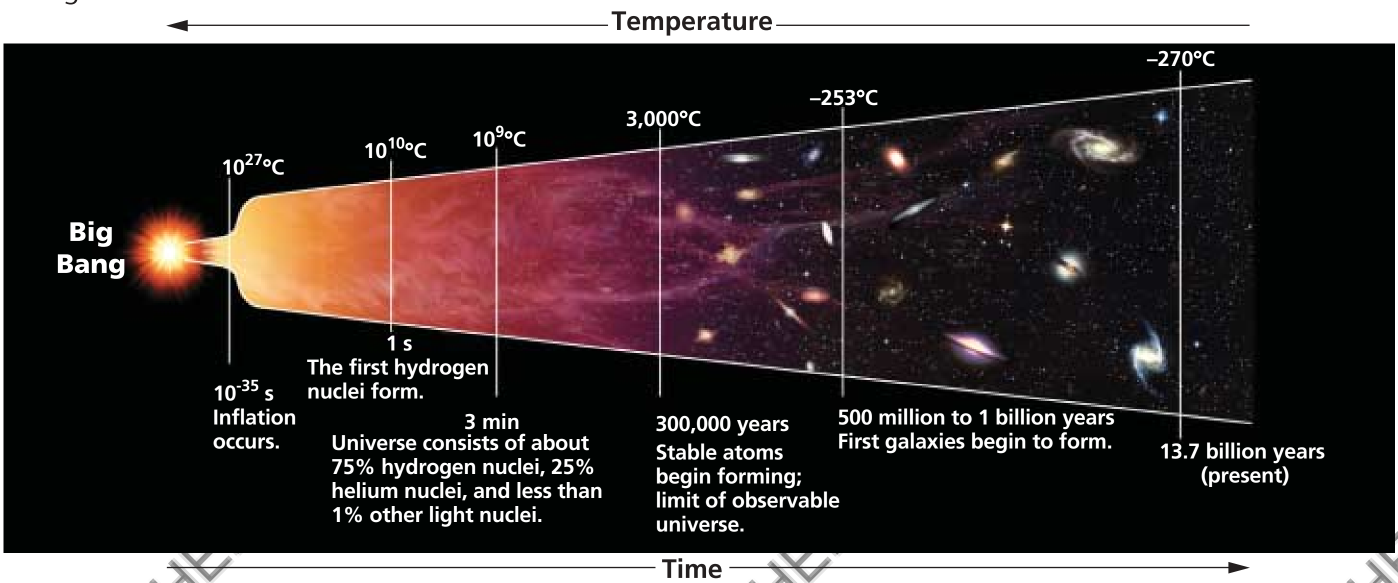
As the universe expanded, some of the matter gathered into clumps that evolved into galaxies. Today, the universe is still expanding, and the galaxies continue to move apart from one another. This expansion of space explains the red shift that we detect in the spectra of galaxies. **Figure 3** shows a timeline of events following the big bang.

By the mid-20th century, almost all astronomers accepted the big bang theory. An important discovery in the 1960s finally convinced most of the remaining scientists that a sudden event, the big bang, had taken place.

big bang theory the theory that all matter and energy in the universe was compressed into an extremely small volume that 13 to 15 billion years ago exploded and began expanding in all directions

Reading Check **What does the big bang theory tell us about the early universe? (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ Following the big bang, matter and energy began to take shape, but the universe as we know it did not begin forming until the temperature cooled by many billions of degrees.



Quick**LAB** time

The Expanding Universe

Procedure

1. Use a **marker** to make 3 dots in a row on an noninflated **balloon.** Label them "A," "B," and "C." Dot B should be closer to A than dot C is to B.
2. Blow the balloon up just until it is taut. Pinch the balloon to keep it inflated, but do not tie the neck.
3. Use **string** and a **ruler** to measure the distances between A and B, B and C, and A and C.
4. With the balloon still inflated, blow into the balloon until its diameter is twice as large.
5. Measure the distances between A and B, B and C, and A and C. For each set of dots, subtract the original distances measured in step 3 from the new distances. Then, divide by 2, because the balloon is about twice as large. This calculation will give you the rate of change for each pair of dots.
6. Repeat steps 4 and 5.

Analysis

1. Did the distance between A and B, between B and C, or between A and C show the greatest rate of change?
2. Suppose dot A represents Earth and that dots B and C represent galaxies. How does the rate at which galaxies are moving away from us relate to how far they are from Earth?

Cosmic Background Radiation

In 1965, researchers using radio telescopes detected **cosmic background radiation,** or low levels of energy evenly distributed throughout the universe. Astronomers think that this background radiation formed shortly after the big bang.

cosmic background radiation radiation uniformly detected from every direction in space; considered a remnant of the big bang

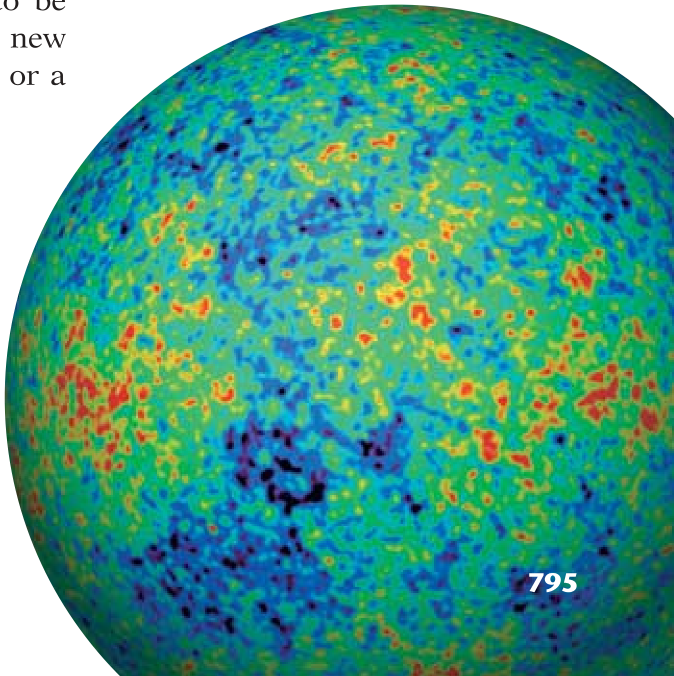
The universe soon after the big bang would have been very hot and would have cooled to a great extent by now. The energy of the background radiation has a temperature of only about 3°C above *absolute zero,* the coldest temperature possible. Because absolute zero is about –273°C, the cosmic background radiation's temperature is about 270°C below zero.

Like any theory, the big bang theory must continue to be tested against each new discovery about the universe. As new information emerges, the big bang theory may be revised, or a new theory may become more widely accepted.

Ripples in Space

Maps of cosmic background radiation over the whole sky look very smooth. But on a map that shows where temperatures differ from the average background temperature, "ripples" become apparent, as shown in **Figure 4.** These ripples are irregularities in the cosmic background radiation, which were caused by small fluctuations in the distribution of matter in the early universe. The ripples may indicate the first stages in the formation of the universe's first galaxies.

Figure 4 ▶ This display is shown on half a globe that represents the sky as seen from Earth. The temperature difference between the red spots and the blue spots is only 2/10,000°C.



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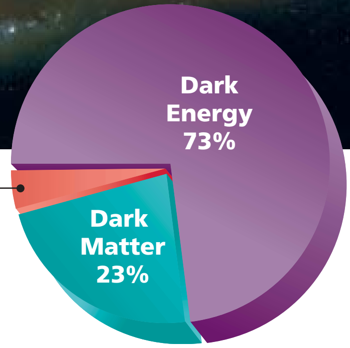

Figure 5 ▶ Studies of the cosmic background radiation show that matter, like that of which you and these spectacular spiral galaxies are made, makes up only 4% of the universe.

A Universe of Surprises

Recent data based on the ripples in the cosmic background radiation and studies of the distance to supernovas found in ancient galaxies have forced astronomers to rethink some of the theories about what makes up the universe. Astronomers now think that the universe is made up of more mass and energy than they can currently detect.

Dark Matter

Surprisingly, analyzing the ripples in the cosmic background radiation tells us that the kinds of matter that humans, the planets, the stars, and the matter between the stars are made of makes up only 4% of the universe, as shown in **Figure 5.** Another 23% of the universe is made up of a type of matter that does not give off light but that has gravity that we can detect. Because this type of matter does not give off light, it is called *dark matter*.

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For a variety of links related to this subject, go to www.scilinks.org

Topic: Big Bang
SciLinks code: HQ60377

Dark Energy

Another surprise is that most of the universe is composed of something that we know almost nothing about. The unknown material is called *dark energy,* and scientists think that it acts as a force that opposes gravity. Recent evidence suggests that distant galaxies are farther from Earth than current theory would indicate. So, many scientists conclude that some form of undetectable dark energy is pushing galaxies apart. Because of dark energy, the universe is not only expanding, but the rate of expansion also seems to be accelerating.

Section 4 Review

1. **Describe** how red shifts were used by cosmologists to determine that the universe is expanding.
2. **Summarize** the big bang theory.
3. **List** evidence that supports the big bang theory.
4. **Compare** the amount of visible matter in the universe with the total amount of matter and energy.

CRITICAL THINKING

5. **Inferring Relationships** How did the distribution of matter in the early universe affect how we are able to detect cosmic background radiation today?
6. **Evaluating Theories** Use the big bang theory to explain why scientists do not expect to find galaxies that have large blue shifts.
7. **Identifying Relationships** Why do observations made of distant galaxies indicate that dark energy exists?

CONCEPT MAPPING

8. Use the following terms to create a concept map: *cosmic background radiation, dark energy, red shift, dark matter, big bang theory,* and *galaxies.*

Chapter 30 Highlights

Sections

1 Characteristics of Stars

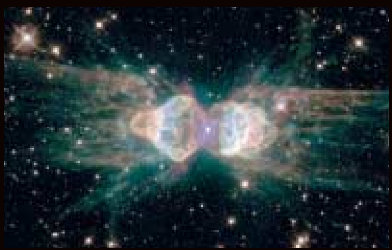
Key Terms

star, 775
Doppler effect, 778
light-year, 779
parallax, 779
apparent magnitude, 780
absolute magnitude, 780

Key Concepts

- To determine the composition and surface temperature of a star, astronomers study the spectrum of the star.
- Stars appear to circle Polaris each night and appear to move westward across the sky on successive nights.
- To measure the distance to a star, astronomers use direct and indirect methods.

2 Stellar Evolution



main sequence, 781
nebula, 782
giant, 784
white dwarf, 785
nova, 786
neutron star, 787
pulsar, 788
black hole, 788

- Plotting stars by temperature and luminosity on the H-R diagram groups stars by their current stage in their life cycles.
- A protostar becomes a star when hydrogen begins to fuse into helium.
- The main-sequence stage is the longest and most stable stage for most stars.
- A red giant is a large, relatively cool star that has a core in which helium fusion is occurring.

3 Star Groups

constellation, 789
galaxy, 790
quasar, 792

- A constellation is a region of the sky that contains a recognizable star pattern and is used to locate celestial objects.
- Astronomers have identified three main types of galaxies: spiral, elliptical, irregular.
- Quasars are very bright, distant galaxies that are thought to have enormous black holes in their centers.

4 The Big Bang Theory

cosmology, 793
big bang theory, 794
cosmic background radiation, 795

- The red shifts of distant galaxies show that the universe is expanding.
- Tracing the expansion backward indicates that everything in the universe was close together about 14 billion years ago.
- Tiny ripples in the temperature of the cosmic background radiation hint that ordinary matter makes up only a small percentage of the universe.

Chapter 30 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *light-year*
2. *cosmology*
3. *big bang theory*

For each pair of terms, explain how the meanings of the terms differ.

4. *constellation* and *cluster*
5. *spiral galaxy* and *elliptical galaxy*
6. *galaxy* and *quasar*
7. *cosmic background radiation* and *red shift*

Understanding Key Concepts

8. The most common element in most stars is
   a. oxygen. **c.** helium.
   b. hydrogen. **d.** sodium.

9. Cosmic background radiation
   a. is very hot.
   b. is blue-green.
   c. comes from supernovas.
   d. comes equally from all directions.

10. Stars appear to move in circular paths through the sky because
    a. Earth rotates on its axis.
    b. Earth orbits the sun.
    c. the stars orbit Polaris.
    d. the Milky Way is a spiral galaxy.

11. A nebula begins the process of becoming a protostar when the nebula
    a. develops a red shift.
    b. changes color from red to blue.
    c. begins to shrink and increases its spin.
    d. explodes as a nova.

12. The brightest star in the night sky is
    a. Polaris. **c.** Arcturus.
    b. Mars. **d.** Sirius.

13. A main-sequence star generates en fusing
    a. nitrogen into iron.
    b. helium into carbon.
    c. hydrogen into helium.
    d. nitrogen into carbon.

14. Which of the following choices list colors of stars from hottest to cool
    a. red, yellow, orange, white, blue
    b. orange, red, white, blue, yellow
    c. yellow, orange, red, blue, white
    d. blue, white, yellow, orange, red

15. The heaviest element formed in th a star is
    a. iron.
    b. carbon.
    c. helium.
    d. nitrogen.

16. The change in position of a nearby seen from different points on Eart compared with the position of a fa star is called
    a. parallax.
    b. blue shift.
    c. red shift.
    d. a Cepheid variable.

Short Answer

17. Describe what scientists think will to the sun in the next 5 billion yea
18. How can a black hole be detected invisible?
19. How does a galaxy that contains a differ from an ordinary galaxy?
20. What evidence indicates that the u expanding?
21. How does the presence of cosmic ground radiation support the big-b theory?

Critical Thinking

22. Inferring Relationships If the spectrum of a star indicates that the star shines with red light, what is the approximate surface temperature of the star?

23. Analyzing Ideas Why are different constellations visible during different seasons?

24. Analyzing Ideas Explain why Polaris is considered to be a very significant star even though it is not the brightest star in Earth's sky.

25. Making Comparisons Why does energy build up more rapidly in a massive protostar than in a less massive one?

26. Analyzing Ideas Explain why an old main-sequence star is made of a higher percentage of helium than a young main-sequence star is.

27. Analyzing Ideas If all galaxies began to show blue shifts, what would this change indicate about the fate of the universe?

Concept Mapping

28. Use the following terms to create a concept map: *galaxy, star, black hole, white dwarf, neutron star, giant, spiral galaxy, supergiant, elliptical galaxy, planetary nebula, main sequence, irregular galaxy,* and *protostar*.

Math Skills

29. Making Calculations The Milky Way galaxy has about 200 billion stars. If only 10% of an estimated 125 billion galaxies thought to exist in the universe were as large as the Milky Way, how many total stars would be in those galaxies?

30. Making Calculations Given that the nearest star is about 4 light-years from Earth and a light-year is about 10,000,000,000,000 km, how many years would it take to travel to the nearest star if your spaceship goes 100 times faster than a car traveling 100 km/h?

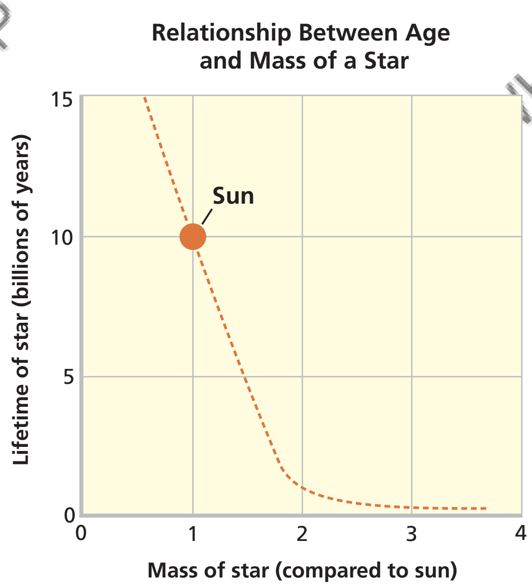
Writing Skills

31. Creative Writing Imagine that you are navigating through the galaxy and seeing many kinds of objects. Write a brief tour article for a magazine that describes your trip.

32. Writing from Research Use the Internet and library resources to research the function of constellations in ancient cultures. Write a short essay describing three different ways that ancient cultures used constellations.

Interpreting Graphics

The graph below shows the relationship between a star's age and mass. Use the graph to answer the questions that follow.



33. Which star would live longer, a star that has half the mass of the sun or a star that has 2 times the mass of the sun?

34. Approximately how long would a main-sequence star that has a mass about 1.5 times that of our sun live?

35. If the mass of the sun was reduced by one-half, approximately how much longer would the sun live than it would with its current mass?

Chapter 30 Standardized Test Prep

Understanding Concepts

Directions (1–5): **For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1. What accounts for different stars being seen in the sky during different seasons of the year?
   A. stellar motion around Polaris
   B. Earth's rotation on its axis
   C. Earth's revolution around the sun
   D. position north or south of the equator

2. How do stellar spectra provide evidence that stars are actually moving?
   F. Dark line spectra reveal a star's composition.
   G. Long exposure photos show curved trails.
   H. Light separates into different wavelengths.
   I. Doppler shifts occur in the star's spectrum.

3. What happens to main sequence stars when energy from fusion is no longer available?
   A. They expand and become supergiants.
   B. They collapse and become white dwarfs.
   C. They switch to fission reactions.
   D. They contract and turn into neutron stars.

4. Which type of star is most likely to be found on the main sequence?
   F. a white dwarf
   G. a red supergiant
   H. a yellow star
   I. a neutron star

5. Evidence for the big-bang theory is provided by
   A. cosmic background radiation
   B. apparent parallax shifts
   C. differences in stellar luminosity
   D. star patterns called constellations

Directions (6–8): **For *each* question, write a short response.**

6. What type of galaxy has no identifiable shape?

7. What is the collective name for the Milky Way galaxy and a cluster of approximately 30 other galaxies located nearby?

8. What is the name for stars that seem to circle around Polaris and never dip below the horizon?

Reading Skills

Directions (9–11): **Read the passage below. Then, answer the questions.**

GEOMAGNETIC POLES

Today, we know that Copernicus was right—the stars are very far from Earth. In fact, stars are so distant that a new unit of length—the light-year—was created to measure their distance. A light-year is a unit of length equal to the distance that light travels through space in 1 year. Because the speed of light through space is about 300,000 km/s, light travels approximately 9.46 trillion kilometers in one year.

Even after astronomers figured out that stars were far from Earth, the nature of the universe was hard to understand. Some astronomers thought that our galaxy, the Milky Way, included every object in space. In the early 1920's, Edwin Hubble made one of the most important discoveries in astronomy. He discovered that the Andromeda galaxy, which is the closest major galaxy to our own, was past the edge of the Milky Way. This fact confirmed the belief of many astronomers that the universe is larger than our galaxy.

9. Why was Edwin Hubble's discovery important?
   A. Hubble's discovery showed scientists that the universe was smaller than previously thought.
   B. Hubble showed that the Andromeda galaxy was larger than the Milky Way galaxy.
   C. Hubble's discovery showed scientists that the universe was larger than our own galaxy.
   D. Hubble showed that all of the stars exist in two galaxies, the Andromeda and the Milky Way.

10. Because the sun and Earth are close together, the distance between the sun and Earth is measured in light-minutes. A light-minute is the distance light travels in 1 minute. The sun is about 8 light-minutes from Earth. What is the approximate distance between the sun and Earth?
    F. 2,400,000 km
    G. 18,000,000 km
    H. 144,000,000 km
    I. 1,000,000,000 km

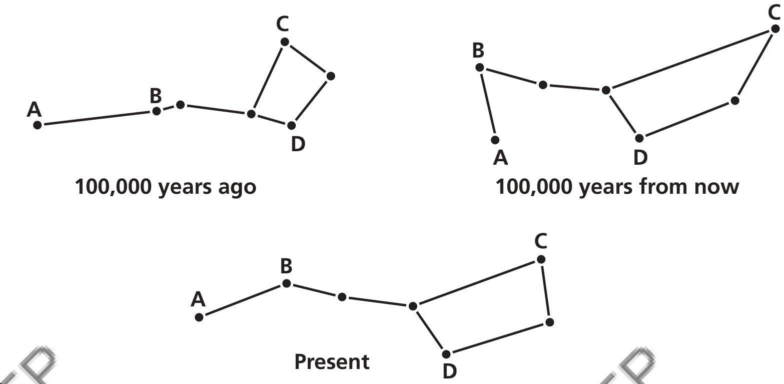
11. Why might scientists use light-years as a measurement of distance between stars?

Interpreting Graphics

Directions (12–15): **For *each* question below, record the correct answer on a separate sheet of paper.**

The diagram shows a group of stars called the Big Dipper moving over a period of 200,000 years. Use this map to answer question 12.

Changing Shape of the Big Dipper over Time



12 What does this series of drawings demonstrate about the individual stars in such a star group?

The table below shows data about several well-known stars. Distance is given in light-years. Use this table to answer questions 13 through 15.

Stellar Characteristics

Name	Color	Magnitude	Distance
Arcturus	orange	0.0	36.8 ly
Betelguese	red	0.5	400 ly
Canopus	yellow-white	-0.6	310 ly
Capella	yellow	0.1	42.2 ly
Mintaka	blue-violet	2.2	915 ly
Rigel	blue-white	0.2	800 ly
Sirius	white	-1.4	8.6 ly
Vega	white	0.0	25.3 ly

13 Which star has the brighest apparent magnitude as seen from Earth?

A. Rigel
B. Betalgeuse
C. Mintaka
D. Sirius

14 Which of these stars is the coolest?

F. Arcturus
G. Betalgeuse
H. Mintaka
I. Vega

15 Which star most likely has a temperature that is similar to the temperature of our sun? Explain how you are able to determine this information.

Test TIP

If you are unsure of an answer, eliminate the answers that you know are wrong before choosing your answer.

Chapter 30 Making Models Lab

Objectives

- **Construct** a model photometer and two model stars.
- **Demonstrate** how distance affects brightness of stars.
- **Explain** how color is related to the temperature of stars.

Materials

- aluminum foil, 12 cm × 12 cm
- batteries, AA (3)
- desk lamp with incandescent bulb
- flashlight bulbs, 3-volt (2)
- paraffin, 12 cm × 6 cm bricks (2)
- rubber band, large
- ruler, metric
- tape, electrical
- wire, plastic-coated with stripped ends, 15 cm
- wire, plastic-coated with stripped ends, 20 cm

Safety

Star Magnitudes

Astronomers study the brightness, or magnitude, of stars. Except for the sun, stars are very faint and visible only at night. Thus, their brightness must be measured with a device called a *photometer*. An astronomical photometer consists of a surface that is sensitive to light and a device that measures the amount of light that reaches the surface. Photometers can also be used to compare the colors of different light sources. In this lab, you will determine the effect of distance on brightness and the relationship between temperature and color.

PROCEDURE

1. Construct two flashlights:

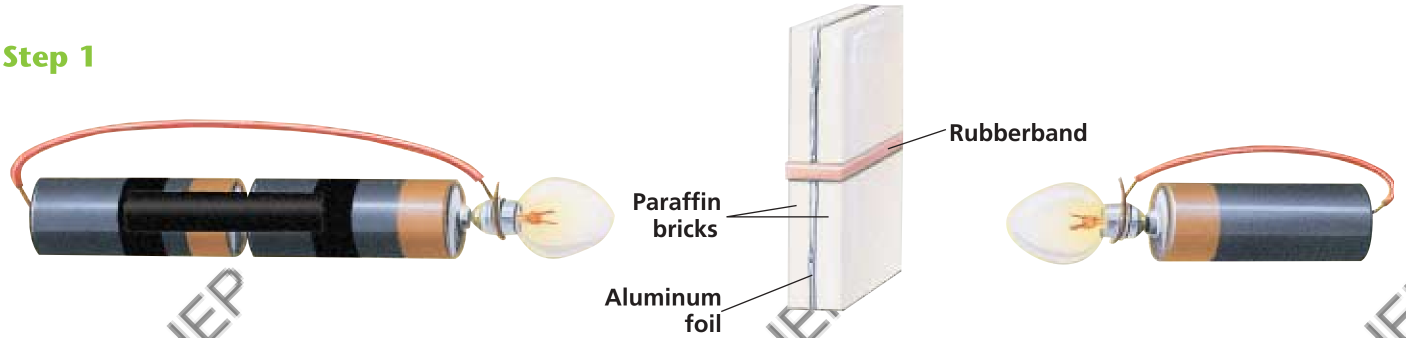
   a. Arrange the bulbs and batteries as shown in the figure below. Using electrical tape, attach the wires to the batteries and bulbs. The bulb should be on. If it is not on, study the illustration again and make adjustments.

   b. Tape the flashlight arrangement together so that it can be moved. Be sure to leave the wire loose at the negative end of the battery so that you can turn your flashlight on and off.

2. Construct a photometer by folding the aluminum foil in half with the shiny side facing out, and place it between two paraffin bricks. Hold the pieces together by using a rubber band.

3. Place the two flashlights about 2 m apart on a table. Place the photometer between them with the largest sides of the bricks facing each flashlight bulb, as shown in the figure below.

Step 1



4 Turn on both flashlights, and turn off all room lights.

5 Move the photometer until both sides are equally bright. Measure the distance, in centimeters, from each flashlight bulb to the center of the photometer. Record these measurements.

6 Square the distances you recorded in step 5. Record these values.

7 Incandescent light bulbs have filaments that emit light at a temperature that is much cooler than the sun's surface. Place the photometer between the desk lamp and a window on a bright day. Sunlight coming through a window will be the same color as the sunlight outdoors. Turn off any fluorescent ceiling lighting, and turn on the desk lamp.

8 Compare the color differences between the paraffin sides of your photometer.

9 Darken the room once again, and compare the colors of the bulb powered by one battery with the colors of the bulb powered by two batteries.

Step 8

ANALYSIS AND CONCLUSION

1 **Analyzing Data** The ratio of the square of the distances you calculated in step 6 is equal to the ratio of the brightnesses of the bulbs. What is the ratio of the square of the distance of the two-battery flashlight to that of the one-battery flashlight? What does this information tell you about the relationship between the brightness of the two flashlights?

2 **Drawing Conclusions** Based on the results of the investigation, would you expect a white star to be hotter or cooler than a yellow star?

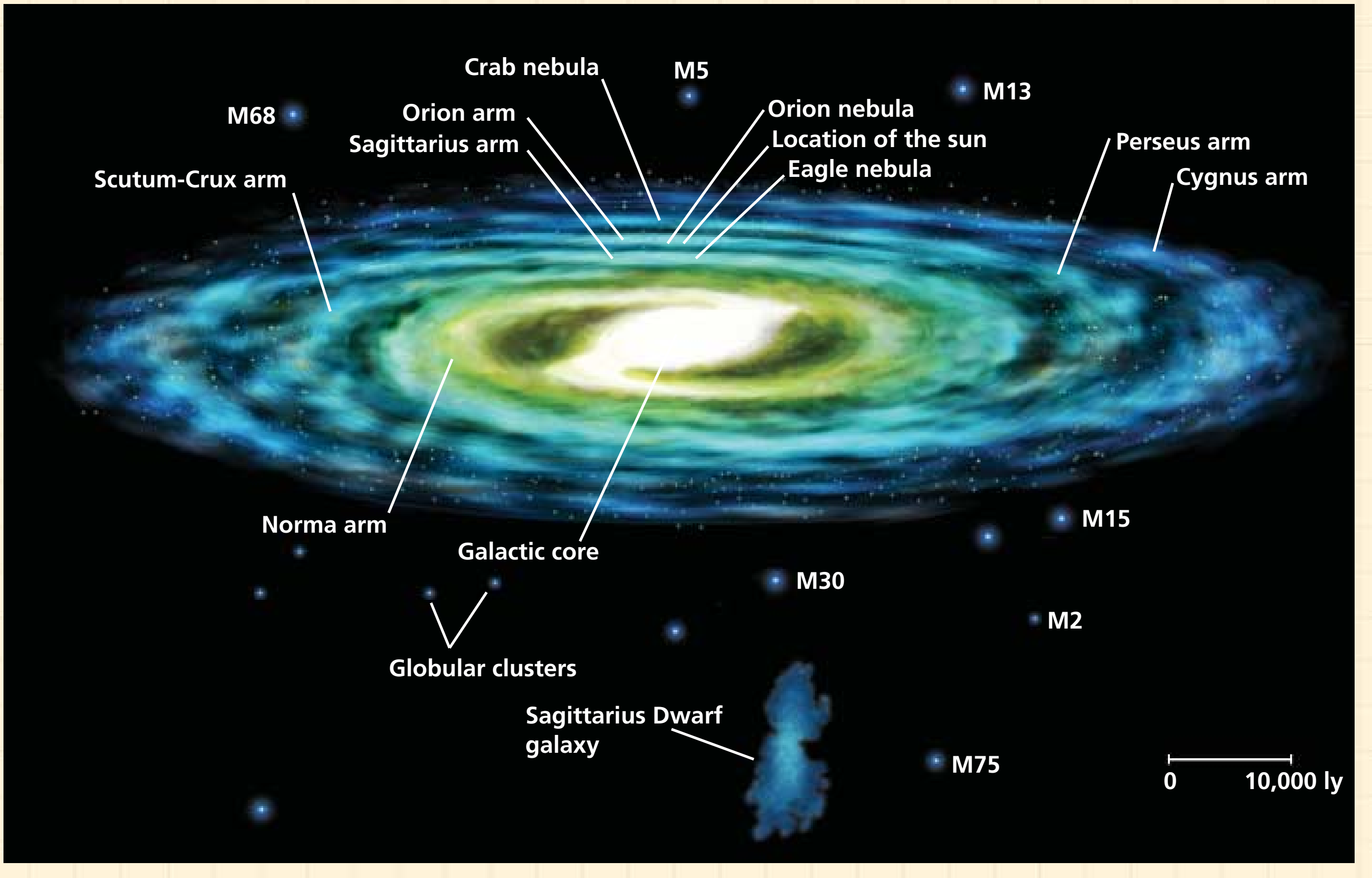
3 **Applying Conclusions** Using your knowledge of the spectrum, would you expect a white star to be hotter or cooler than an orange star? Predict whether a blue star is hotter or cooler than a white star. Also, predict whether a red star is hotter or cooler than an orange star.

Extension

1 **Explaining Observations** Find an incandescent bulb controlled by a dimmer. Watch the color of the light as it fades. Does it become more yellow or more white? Explain why.

MAPS in Action

The Milky Way



Map Skills Activity

The map above shows what astronomers think the Milky Way galaxy looks like. Because of Earth's position within the galaxy, scientists must hypothesize what our galaxy looks like from a perspective outside of the galaxy. They must also form a hypothesis about the shape and location of those spiral arms that are obscured by either the galactic core or other spiral arms that are closer to Earth. Use the map to answer the questions below.

1. **Using the Key** What is the approximate distance from one edge of the Milky Way to the other edge?

2. **Using the Key** What is the approximate width of the galactic core?

3. **Analyzing Relationships** How are the Perseus arm and the Cygnus arm related to the Norma arm?

4. **Identifying Trends** What happens to the arms of the Milky Way as they radiate outward from the center of the galaxy?

5. **Analyzing Relationships** The locations on the map marked with an M and a number are known as Messier objects. These objects are named for their discoverer, Charles Messier, who first catalogued them in the 1700s. The Messier objects shown on this map are all globular clusters. If each of these clusters contain hundreds, or even thousands, of stars, why might the clusters appear so small on this map compared to the size of the Milky Way?

SCIENCE AND TECHNOLOGY

Studying Stars in Formation

When stars are forming, they have a dim, reddish glow. As their temperature increases, they eventually become much hotter and brighter. But when they are dim and reddish, they give off most of their light in the infrared part of the spectrum. Most of this infrared light does not penetrate Earth's atmosphere, where water vapor and carbon dioxide block the light. So, astronomers have launched telescopes into space that allow them to observe stars and galaxies from above the layers of Earth's atmosphere.

The *Hubble Space Telescope*

The *Hubble Space Telescope* observes ultraviolet, visible, and infrared spectra. The telescope did not have infrared capability at first. But a camera called NICMOS, which stands for *Near Infrared Camera and Multi-Object Spectrometer,* was launched on an updating mission in which astronauts brought new equipment to the *Hubble Space Telescope*. Infrared cameras such as NICMOS have to be kept very cool, and the liquid nitrogen that originally cooled NICMOS was depleted after about two years. The next mission to the *Hubble Space Telescope* brought a new type of refrigerator to keep the camera cool.

The *Spitzer Space Telescope*

On August 25, 2003, NASA launched a new and more sensitive infrared telescope. Originally called *Space Infrared Telescope Facility,* it was renamed the *Spitzer Space Telescope*. This telescope is not orbiting Earth in the way that the *Hubble Space Telescope* does. Instead, it is far from Earth and trails Earth in its orbit around the sun. This keeps the light reflected by Earth from heating the camera.

▲ Astronauts conduct delicate repairs to the *Hubble Space Telescope* while in orbit.

The *Spitzer Space Telescope* takes images of infrared light, which has wavelengths as much as 100 times longer than the wavelengths in images taken by the *Hubble Space Telescope*. The *Spitzer Space Telescope's* high-quality images show glowing dust, cool stars, and the most distant galaxies especially well.

◀ This false-color image from the *Spitzer Space Telescope* shows the intensity of infrared emissions of the galaxy M81.

Extension

1. **Making Comparisons** What types of information can scientists determine from infrared images that they cannot determine from images taken in the visual spectrum?

APPENDIX CONTENTS

Items marked with an oak leaf contain information directly related to environmental issues.

Analyzing Science Terms

You can unlock the meaning of an unfamiliar science term by analyzing its word parts. Many parts of scientific words carry a meaning that derives from Latin or Greek. The parts of words listed below provide clues to the meanings of many science terms.

Word part or root	Meaning	Application
a-	not, without	abiotic
astr-, aster-	star	astronomy
bar-, baro-	weight, pressure	barometer
batho-, bathy-	depth	batholith, bathysphere
circum-	around	circum-Pacific, circumpolar
-cline	lean, slope	anticline, syncline
-duct-	to lead, draw	conduction
eco-	environment	ecology, ecosystem
epi-	on	epicenter
ex-, exo-	out, outside of	exosphere, exfoliation, extrusion
geo-	earth	geode, geology, geomagnetic
-graph	write, writing	seismograph
hydro-	water	hydrosphere
hypo-	under	hypothesis
iso-	equal	isoscope, isostasy, isotope
-lith, -lithic	stone	Neolithic, regolith
-log-	study	ecology, geology, meteorology
magn-	great, large	magnitude
mar-	sea	marine
meta-	among, change	metamorphic, metamorphism
-meter	to measure	thermometer, spectrometer
micro-	small	microquake
-morph, -morphic	form, shape	metamorphic
nebula-	mist, cloud	nebula
neo-	new	Neolithic
paleo-	old	paleontology, Paleozoic
ped-, pedo-	ground, soil	pediment
per-	through	permeable
peri-	around	perigee, perihelion
seism-, seismo-	shake, earthquake	seismic, seismograph
sol-	sun	solar, solstice
spectro-	look at, examine	spectroscope, spectrum
-sphere	ball, globe	geosphere, lithosphere
strati-, strato-	spread, layer	stratification, stratovolcano
terra-	earth, land	terracing, terrane
thermo-	heat	thermosphere, thermometer
top-, topo-	place	topographic
trop-, tropo-	turn, respond to	tropopause, troposphere

How to Make Power Notes

Power notes help you organize the Earth science concepts you are studying by distinguishing main ideas from details. Similar to outlines, power notes are linear in form and provide you with a framework of important concepts. To make power notes, you assign a *power* of 1 to each main idea and a 2, 3, or 4 to each detail. You can use power notes to organize ideas while reading your text or to restructure your class notes for studying purposes. Practice first by using simple concepts. For example, start with a few headers or bold-faced vocabulary terms from this book. Later, you can strengthen your notes by expanding these simple words into more-detailed phrases and sentences. Use the following general format.

Power 1: Main idea
- Power 2: Detail or support for Power 1 idea
  - Power 3: Detail or support for Power 2 concept
    - Power 4: Detail or support for Power 3 concept

1 Pick a Power 1 word or phrase from the text.

The text you choose does not have to come from your Earth science textbook. You may make power notes from your lecture notes or from another source. We'll use the term *environmental problems* as an example of a main idea.

Power 1: environmental problems

2 Using the text, select some Power 2 words to support your Power 1 word.

We'll use the terms *resource depletion, pollution,* and *extinction,* which are the three main types of environmental problems.

Power 1: environmental problems
- Power 2: resource depletion
- Power 2: pollution
- Power 2: extinction

3 Select some Power 3 words to support your Power 2 words.

We'll use the terms *renewable resources* and *nonrenewable resources*. These two terms are related to *resource depletion,* which is one of the Power 2 concepts.

Power 1: environmental problems
- Power 2: resource depletion
  - Power 3: renewable resources
  - Power 3: nonrenewable resources
- Power 2: pollution
- Power 2: extinction

4 Continue to add powers to support and detail the main idea as necessary.

There are no restrictions on how many power numbers you can add to help you extend and organize your ideas. Words that have the same power number should have a similar relationship to the previous power but do not have to be related to each other.

Power 1: environmental problems
- Power 2: resource depletion
  - Power 3: renewable resources
  - Power 3: nonrenewable resources
- Power 2: pollution
  - Power 3: degradable pollutants
  - Power 3: nondegradable pollutants
- Power 2: extinction
  - Power 3: pollution
  - Power 3: habitat loss

Practice

1. Use this book's lesson on scientific methods and power notes structure to organize the following terms: *observing, hypothesizing and predicting, experimenting, organizing and analyzing data, drawing conclusions, repeating experiments, communicating results, observation, hypothesis, prediction, experiment, variable, experimental group, control group,* and *data.*

(See the last page of the Skills Handbook for the answers to practice problems.)

SKILLS HANDBOOK

How to Make KWL Notes

KWL stands for *what I **K**now, what I **W**ant to know,* and *what I **L**earned*. The KWL strategy is somewhat different from other learning strategies because it prompts you to brainstorm about the subject matter before reading the assigned material. Relating new ideas and concepts with those that you have learned will help you to understand and apply the knowledge you obtain in this course. The section objectives throughout your text are ideal for using the KWL strategy. Read the objectives before reading each section, and follow the instructions in the example below.

1 Read the section objectives.

You may also want to scan headings, boldfaced terms, and illustrations in the section. We'll use a few sample objectives as examples.

- List and describe the steps of the scientific method.
- Describe why a good hypothesis is not simply a guess.
- Describe the two essential parts of a good experiment.

2 Divide a sheet of paper into three columns. Label the columns "What I know," "What I want to know," and "What I learned."

Here is an example table:

What I know	What I want to know	What I learned

3 Brainstorm about what you know about the information in the objectives, and write these ideas in the first column.

Because this table is designed to help you blend your knowledge with new information, you do not have to write complete sentences.

4 Think about what you want to know about the information in the objectives. Write these ideas in the second column.

You'll want to know the information you will be tested on, so include information from both the objectives and any other topics your teacher has given to you.

5 Use the third column to write down the information you learned. Do this while you read the text or just after reading the text.

While you read, pay close attention to any information about the topics you wrote in the column entitled "What I want to know." If you do not find all of the answers you are looking for, you may need to reread the text or reference a second source. Be sure to ask your teacher for help if you cannot find the information after reading the text a second time.

When you have completed reading the text, review the ideas you brainstormed. Compare your ideas in the first column with the information you wrote down in the third column. If you find that some of the ideas are incorrect, cross them out. Before you begin studying for your test, identify and correct any misconceptions you had prior to reading.

Here is an example of what your notes might look like after using the KWL strategy:

What I know	What I want to know	What I learned
• The steps of the experimental method are predict, test, and conclude.	• What are the steps of the experimental method?	• The steps of the experimental method are observing, hypothesizing, experimenting, organizing and analyzing data, drawing conclusions, communicating results, and repeating experiments.
• A hypothesis is similar to a guess, but when you form a hypothesis, you have an idea of what might happen.	• Why is a hypothesis not a guess?	• A hypothesis is more than a guess. You have to base a hypothesis on observations and really think about what you are trying to learn. You should also design an experiment that can test if your hypothesis is wrong, but an experiment cannot prove that your hypothesis is correct.
• A good experiment includes a hypothesis and a lot of equipment.	• What are the two important parts of a good experiment?	• The two important parts of a good experiment are a single variable and a control group.

Practice

1. Use the third column from the table above to identify and correct any misconceptions in the following list of ideas.
  a. The first step of the experimental method is to predict.
  b. A hypothesis is similar to a guess.
  c. A good experiment includes a lot of equipment.

(See the last page of the Skills Handbook for the answers to practice problems.)

How to Make Two-Column Notes

Two-column notes can be used to learn and review definitions of vocabulary terms, examples of multiple-step processes, or details of specific concepts. The two-column note strategy is simple: write the term, main idea, step-by-step process, or concept in the left-hand column, and write the definition, example, or detail on the right.

One strategy for using two-column notes is to organize main ideas and their details. You will write the main ideas from your reading in the left-hand column of your paper. You can write these ideas as questions, key words, or a combination of both. Then, write details that describe these main ideas in the right-hand column of your paper.

1 Identify the main ideas.

The main ideas for a chapter are listed in the section objectives. However, you decide which ideas to include in your notes. The example below shows some main ideas from possible objectives in a section of this book.

- *Define Earth science, and compare Earth science with geology.*
- *List the four major fields of study that contribute to Earth science.*

2 Divide a blank sheet of paper into two columns, and write the main ideas in the left-hand column.

Remind yourself that your two-column notes are precisely that—notes. Do not copy whole phrases out of the book or waste your time writing ideas in complete sentences. Summarize your ideas by using short phrases that are easy for you to understand and remember. Decide how many details you need for each main idea, and write that number in parentheses under the main idea.

Main idea	Detail notes
Earth science (two definitions)	
Goals of Earth science (one main goal)	
What is studied (two main areas)	
Related fields of study (four major fields)	

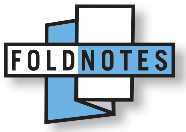
3 Write the detail notes in the right-hand column.

List as many details as you designated in the main-idea column.

Main idea	Detail notes
Earth science (two definitions)	Earth science is the study of Earth and the universe around it. Scientific methods are the organized, logical approaches to scientific research.
Goals of Earth science (one main goal)	to understand Earth and the universe around it
What is studied (two main areas)	Earth and the universe around it • the origin, history, and structure of the solid Earth and the processes that shape it • how Earth's atmosphere, oceans, and land interact
Related fields of study (four major fields)	geology • the study of the origin, history, and structure of Earth and the processes that shape it oceanography • the study of Earth's oceans, including waves, tides, ocean currents, the ocean floor, and life in the oceans meteorology • the study of Earth's atmosphere, including weather and climate astronomy • the study of the universe beyond Earth, including planets, stars, and galaxies

You can use two-column notes to study for a short quiz or for a test on the material in an entire chapter. Cover the information in the right-hand column with a sheet of paper. Recite what you know, and then uncover the notes to check your answers. Then, ask yourself what else you know about that topic. Linking ideas in this way will help you gain a more complete picture of Earth science.

SKILLS HANDBOOK FoldNote Instructions

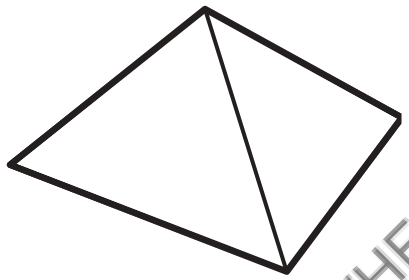


Have you ever tried to study for a test or quiz but didn't know where to start? Or have you read a chapter and found that you can remember only a few ideas? Well, FoldNotes are a fun and exciting way to help you learn and remember the ideas you encounter as you learn science!

FoldNotes are tools that you can use to organize concepts. One FoldNote focuses on a few main concepts. FoldNotes help you learn and remember how the concepts fit together. FoldNotes can help you see the "big picture." Below, you will find instructions for building 10 different FoldNotes.

Pyramid

1. Place a **sheet of paper** in front of you. Fold the lower left-hand corner of the paper diagonally to the opposite edge of the paper.
2. Cut off the tab of paper created by the fold (at the top).
3. Open the paper so that it is a square. Fold the lower right-hand corner of the paper diagonally to the opposite corner to form a triangle.
4. Open the paper. The creases of the two folds will have created an X.
5. Using **scissors,** cut along one of the creases. Start from any corner, and stop at the center point to create two flaps. Use **tape** or **glue** to attach one of the flaps on top of the other flap.

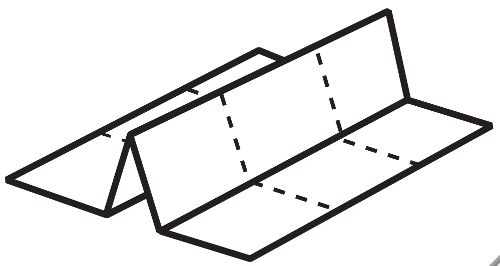


Double-Door Fold

1. Fold a **sheet of paper** in half from the top to the bottom. Then, unfold the paper.
2. Fold the top and bottom edges of the paper to the center crease.

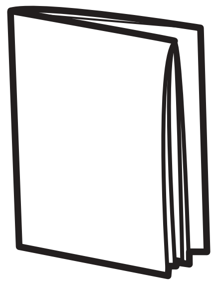
Table Fold

1. Fold a **piece of paper** in half from the top to the bottom. Then, fold the paper in half again.
2. Fold the paper in thirds from side to side.
3. Unfold the paper completely. Carefully trace the fold lines by using a pen or pencil.



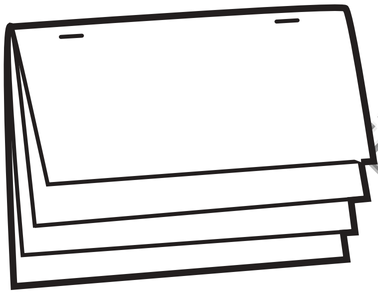
Booklet

1. Fold a **sheet of paper** in half from left to right. Then, unfold the paper.
2. Fold the sheet of paper in half again from the top to the bottom. Then, unfold the paper.
3. Refold the sheet of paper in half from left to right.
4. Fold the top and bottom edges to the center crease.
5. Completely unfold the paper.
6. Refold the paper from top to bottom.
7. Using **scissors,** cut a slit along the center crease of the sheet from the folded edge to the creases made in step 4. Do not cut the entire sheet in half.
8. Fold the sheet of paper in half from left to right. While holding the bottom and top edges of the paper, push the bottom and top edges together so that the center collapses at the center slit. Fold the four flaps to form a four-page book.



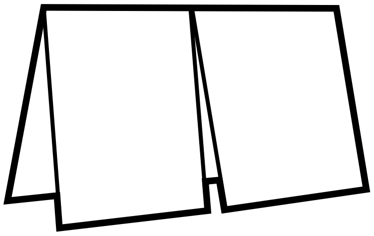
Layered Book

1. Lay **one sheet of paper** on top of **another sheet.** Slide the top sheet up so that 2 cm of the bottom sheet is showing.
2. Holding the two sheets together, fold down the top of the two sheets so that you see four 2 cm tabs along the bottom.
3. Using a **stapler,** staple the top of the FoldNote.



Two-Panel Flip Chart

1. Fold a **piece of paper** in half from the top to the bottom.
2. Fold the paper in half from side to side. Then, unfold the paper so that you can see the two sections.
3. From the top of the paper, cut along the vertical fold line to the fold in the middle of the paper. You will now have two flaps.

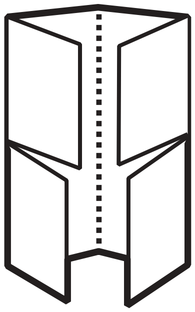


SKILLS HANDBOOK

Key-Term Fold

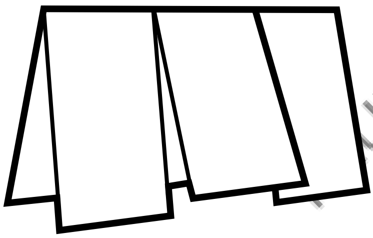
1. Fold a **sheet of lined notebook paper** in half from left to right.
2. Using **scissors,** cut along every third line from the right edge of the paper to the center fold to make tabs.

Four-Corner Fold



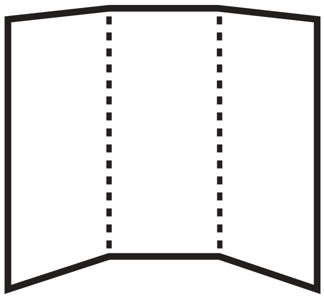
1. Fold a **sheet of paper** in half from left to right. Then, unfold the paper.
2. Fold each side of the paper to the crease in the center of the paper.
3. Fold the paper in half from the top to the bottom. Then, unfold the paper.
4. Using **scissors,** cut the top flap creases made in step 3 to form four flaps.

Three-Panel Flip Chart



1. Fold a **piece of paper** in half from the top to the bottom.
2. Fold the paper in thirds from side to side. Then, unfold the paper so that you can see the three sections.
3. From the top of the paper, cut along each of the vertical fold lines to the fold in the middle of the paper. You will now have three flaps.

Tri-Fold



1. Fold a piece a paper in thirds from the top to the bottom.
2. Unfold the paper so that you can see the three sections. Then, turn the paper sideways so that the three sections form vertical columns.
3. Trace the fold lines by using a **pen** or **pencil.** Label the columns “Know,” “Want,” and “Learn.”

SKILLS HANDBOOK Graphic Organizer Instructions

Graphic Organizer

Have you ever wished that you could draw the many concepts you learn in your science class? Sometimes, being able to see how concepts are related helps you remember what you've learned. Graphic Organizers help you see the concepts! They are a way to draw or map out concepts.

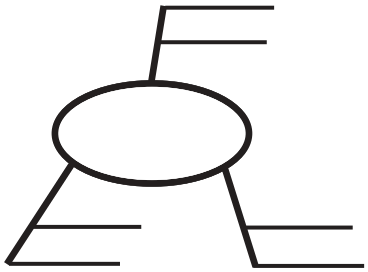
You need only a piece of paper and a pencil to make a Graphic Organizer. Below, you will find instructions for six different Graphic Organizers that are designed to help you organize the concepts you'll learn in this book.

Spider Map

1. Draw a diagram like the one shown. In the circle, write the main topic.

2. From the circle, draw legs to represent different categories of the main topic. You can have as many categories as you want.

3. From the category legs, draw horizontal lines. As you read the chapter, write details about each category on the horizontal lines.

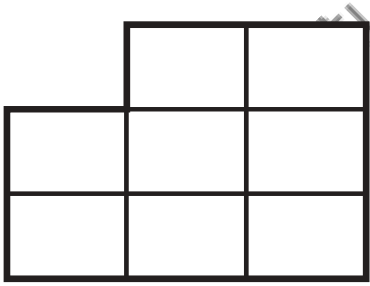


Comparison Table

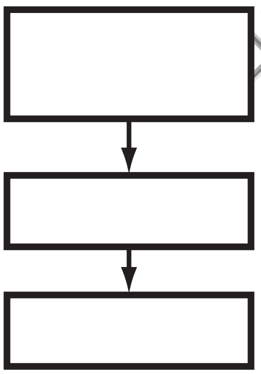
1. Draw a chart like the one shown. Your chart can have as many columns and rows as you want.

2. In the top row, write the topics that you want to compare.

3. In the left column, write characteristics of the topics that you want to compare. As you read the chapter, fill in the characteristics for each topic in the appropriate boxes.

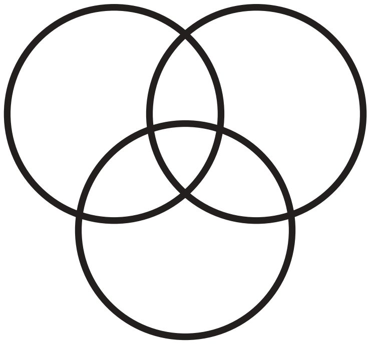


Chain-of-Events-Chart



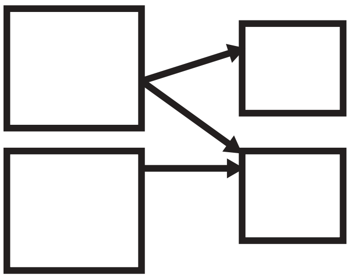
1. Draw a box. In the box, write the first step of a process or the first event of a timeline.
2. Under the box, draw another box, and use an arrow to connect the two boxes. In the second box, write the next step of the process or the next event in the timeline.
3. Continue adding boxes until the process or timeline is finished.

Venn Diagram



1. Draw a diagram like the one shown. You may have two or three circles depending on the number of topics. Make sure the circles overlap with each other.
2. In each circle, write a topic that you want to compare with a topic in another circle.
3. In the areas of the diagram where circles overlap, fill in characteristics that the topics in the overlapping circles share.
4. In the areas of the diagram where circles do not overlap, fill in characteristics that are unique to the topic of the particular circle.

Cause-and-Effect Map



1. Draw a box, and write a cause in the box. You can have as many cause boxes as you want. The diagram shown here is one example of a cause-and-effect map.
2. Draw another box to represent an effect of the cause. You can have as many effect boxes as you want. Draw a line from each cause to the effect(s).
3. In the cause boxes, write a description, explanation, or details about the cause. In the effect boxes, explain the effects that result from the process or factor identified in the cause box.

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Concept Map

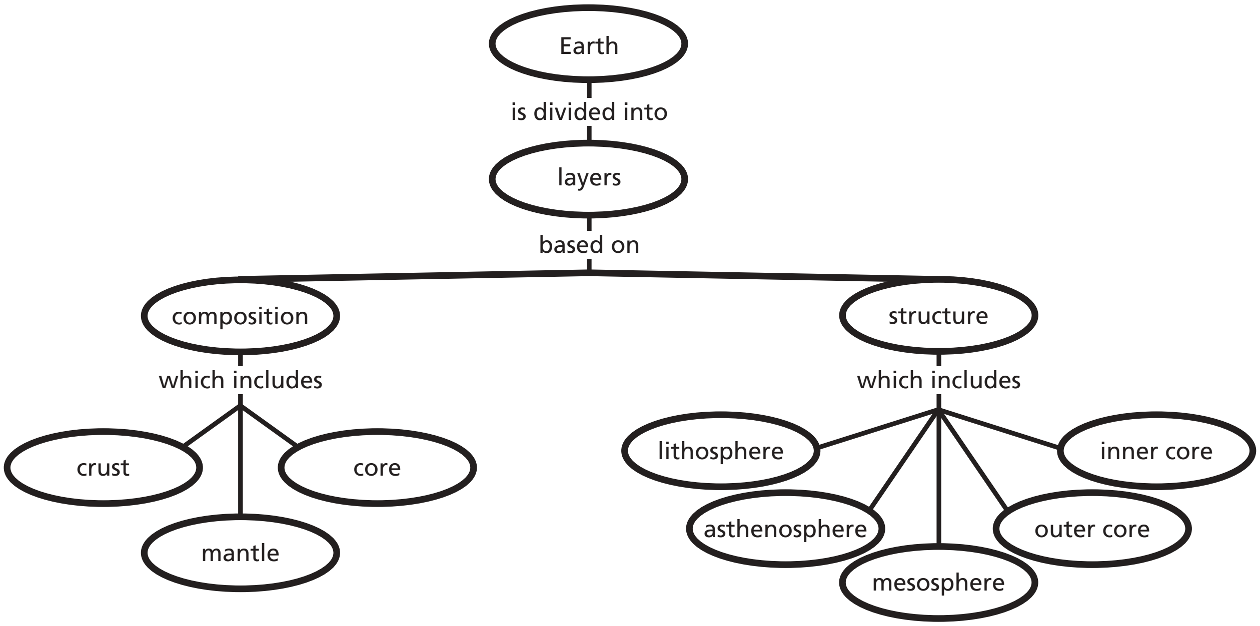
A concept map is a simple drawing that shows how concepts are connected to each other. Concept maps may be a good tool for visual learners to use when studying and to use to test their understanding of information in the text. Concept maps may be based on key vocabulary terms from the text. These terms are usually nouns, which make good labels for major concepts. Linking words may be used to explain relationships. A group of connected words and lines show a proposition. A proposition is another way of stating a main idea or explaining a concept.

1. Identify main ideas from the text, and write those ideas as short phrases or single words. Concepts may be vocabulary terms, important phrases, or descriptions of processes.

2. List all of the important concepts. Select a main concept for the map, and place this concept at the top or center of a piece of paper.

3. Build the map by placing the other concepts under or around the main concept, according to their importance or their relationship to the main concept.

4. Draw lines between the concepts to show relationships between ideas. Add linking words to give meaning to the arrangement of concepts. To distinguish concepts from links, place concepts in circles, ovals, or rectangles.



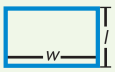
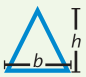
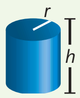
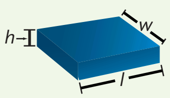
SKILLS HANDBOOK Math Skills Refresher

Geometry

A useful way to model the objects and substances studied in science is to consider them in terms of their shapes. For example, many of the properties of a wheel can be understood by pretending that the wheel is a perfect circle.

When you use shapes as models, the ability to calculate the area or volume of shapes is a useful skill. The table below provides equations for the area and volume of several geometric shapes.

Geometric Areas and Volumes

Geometric shape		Equations for shape
Rectangle		*area* = lw
Circle		*area* = πr^2 *circumference* = $2\pi r$
Triangle		*area* = $\frac{1}{2}bh$
Sphere		*surface area* = $4\pi r^2$ *volume* = $\frac{4}{3}\pi r^3$
Cylinder		*surface area* = $2\pi r^2 + 2\pi rh$ *volume* = $\pi r^2 h$
Rectangular box		*surface area* = $2(lh + lw + hw)$ *volume* = lwh

Practice

1. Calculate the area of a triangle that has a base of 900.0 m and a height of 500.0 m.
2. What is the volume of a cylinder that has a diameter of 14 cm and a height of 8 cm?
3. Calculate the surface area of a cube that has sides that are 4 cm long.

(See the last page of the Skills Handbook for the answers to practice problems.)

Exponents

An exponent is a number that is written as superscript to the right of another number. The best way to explain how an exponent works is by using an example. In the value 5^4, the 4 is the exponent of the 5. The number and its exponent means that 5 is multiplied by itself 4 times as shown below:

$$5^4 = 5 \times 5 \times 5 \times 5 = 625$$

Exponents are also referred to as *powers*. Using this terminology, the above equation could be read "five to the fourth power equals 625," or "five to the power of four equals 625." Keep in mind that any number raised to the power of 0 is equal to 1: $5^0 = 1$. Also, any number raised to the power of 1 is equal to itself: $5^1 = 5$.

A scientific calculator is very helpful for solving most problems involving exponents. Many calculators have keys for squares and square roots, but scientific calculators usually have a special caret key, ^, for entering exponents. If you type in "5^4" and then press the equals sign or Enter, the calculator will determine that $5^4 = 625$ and display the answer 625.

Exponents

	Rule	Example
Zero power	$x^0 = 1$	$7^0 = 1$
First power	$x^1 = x$	$6^1 = 6$
Multiplication	$(x^n)(x^m) = (x^{n+m})$	$(x^2)(x^4) = x^{(2+4)} = x^6$
Division	$\frac{x^n}{x^m} = x^{(n-m)}$	$\frac{x^8}{x^2} = x^{(8-2)} = x^6$
Exponents raised to a power	$(x^n)^m = x^{nm}$	$(5^2)^3 = 5^6 = 15,625$

Practice

1. Perform the following calculations:
   a. $9^1 =$
   b. $(3^3)^5 =$
   c. $(14^2)(14^3) =$
   d. $11^0 =$

(See the last page of the Skills Handbook for the answers to practice problems.)

Order of Operations

Use this phrase to remember the correct order for long mathematical problems: "Please Excuse My Dear Aunt Sally." Some people just remember the acronym "PEMDAS". This acronym stands for *parentheses, exponents, multiplication, division, addition,* and *subtraction*. This is the correct order in which to complete mathematical operations. These rules are summarized in the table below.

Order of Operations

1. Simplify groups inside parentheses. Start with the innermost group and work out.
2. Simplify all exponents.
3. Perform multiplication and division in order from left to right.
4. Perform addition and subtraction in order from left to right.

Look at the following example.

$$4^3 + 2 \times [8 - (3 - 1)] = ?$$

First, simplify the operations inside parentheses. Begin with the innermost parentheses:

$$(3 - 1) = 2$$

$$4^3 + 2 \times [8 - 2] = ?$$

Then, move on to the next-outer parentheses:

$$[8 - 2] = 6$$

$$4^3 + 2 \times 6 = ?$$

Now, simplify all exponents:

$$4^3 = 64$$

$$64 + 2 \times 6 = ?$$

Next, perform the remaining multiplication:

$$2 \times 6 = 12$$

$$64 + 12 = ?$$

Finally, perform the addition:

$$64 + 12 = 76$$

Practice

1. $2^3 \div 2 + 4 \times (9 - 2^2) =$
2. $\dfrac{2 \times (6-3) + 8}{4 \times 2 - 6} =$

(See the last page of the Skills Handbook for the answers to practice problems.)

Algebraic Rearrangements

Algebraic equations contain *constants* and *variables*. Constants are simply numbers, such as 2, 5, and 7. Variables are represented by letters such as x, y, z, a, b, and c. Variables are unspecified quantities and are also called the *unknowns*. Often, you will need to determine the value of a variable in an equation that contains algebraic expressions.

An algebraic expression contains one or more of the four basic mathematical operations: addition, subtraction, multiplication, and division. Constants, variables, or terms made up of both constants and variables can be involved in the basic operations.

The key to finding the value of a variable in an algebraic equation is that the total quantity on one side of the equals sign is equal to the quantity on the other side. If you perform the same operation on either side of the equation, the results will still be equal. To determine the value of a variable in an algebraic expression, you try to reduce the equation into a simple value that tells you exactly what x (or some other variable) equals.

Look at the simple problem below:

$$8x = 32$$

If you wish to solve for x, you can multiply or divide each side of the equation by the same factor. You can perform any operation on one side of an equation as long as you do the same thing to the other side of the equation. In this example, if you divide both sides of the equation by 8, you have the following:

$$\frac{8x}{8} = \frac{32}{8}$$

The two 8s on the left side of the equation cancel each other out, and the fraction $\frac{32}{8}$ can be reduced to give the whole number *4*. Therefore, $x = 4$.

Next, consider the following equation:

$$2x + 4 = 16$$

If you divide each side by 2, you are left with $x + 2$ on the left and 8 on the right:

$$x + 2 = 8$$

Now, you can subtract 2 from each side of the equation to find that $x = 6$. In all cases, the operation that is performed on the left side of the equals sign must also be performed on the right side.

Practice

1. Rearrange each of the following equations to give the value of the variable indicated with a letter.

a. $8x - 32 = 128$

b. $6 - 5(4a + 3) = 26$

c. $-3(y - 2) + 4 = 29$

d. $-2(3m + 5) = 14$

e. $\left[8\frac{(8+2z)}{32}\right] + 2 = 5$

f. $\frac{(6b + 3)}{3} - 9 = 2$

(See the last page of the Skills Handbook for the answers to practice problems.)

Scientific Notation

Many quantities that scientists deal with are very large or very small values. For example, light travels at about 300,000,000 m/s, and an electron has a mass of about 0.000 000 000 000 000 000 000 000 000 0009 g. Obviously, it is difficult to read, write, and keep track of numbers such as these. We avoid this problem by using a method that deals with powers of the number 10.

Study the positive powers of 10 shown in the following table. You should be able to check these numbers by using what you know about exponents. The number of zeros in the equivalent number corresponds to the exponent of the 10, or the power to which the 10 is raised. The equivalent of 10^4 is 10,000, so the number has four zeros.

But how can we use the powers of 10 to simplify large numbers such as the speed of light? The speed of light is equal to $3 \times 100{,}000{,}000$ m/s. The factor of 10 in this number has 8 zeros, so the number can be rewritten as 10^8. So, 300,000,000 can be expressed as 3×10^8.

Powers of 10

Power of 10	Decimal equivalent
10^4	10,000
10^3	1,000
10^2	100
10^1	10
10^0	1
10^{-1}	0.1
10^{-2}	0.01
10^{-3}	0.001

Negative exponents can be used to simplify numbers that are less than 1. Study the negative powers of 10 in the table above. In these cases, the exponent of 10 equals the number of decimal places you must move the decimal point to the right so that there is one digit just to the left of the decimal point. In the case of the mass of an electron, the decimal point has to be moved 28 decimal places to the right for the numeral 9 to be just to the left of the decimal point. The mass of the electron, about 0.000 000 000 000 000 000 000 000 000 0009 g, can be rewritten as about 9×10^{-28} g.

Scientific notation is a way to express numbers as a power of 10 multiplied by another number that has only one digit to the left of the decimal point. For example, 5,943,000,000 is written as 5.943×10^9 when expressed in scientific notation. The number 0.000 0832 is written as 8.32×10^{-5} when expressed in scientific notation.

Practice

1. Rewrite the following values using scientific notation.

a. 12,300,000 m/s

b. 0.000 000 000 0045 kg

c. 0.000 0653 m

d. 55,432,000,000,000 s

e. 273.15 K

f. 0.000 627 14 kg

(See the last page of the Skills Handbook for the answers to practice problems.)

Significant Digits

The following list can be used to review how to determine the number of *significant digits* (also called *significant figures*) in a given value or measurement. Significant digits are shown in red below.

Rules for Significant Digits:

1. All nonzero digits are significant. For example, 1,246 has four significant digits.
2. Any zeros between significant digits are also significant. For example, 1,206 has four significant digits.
3. Zeros at the end of a number but to the left of a decimal are significant if they have been measured or are the first estimated digit; otherwise, they are not significant. In this book, they will be treated as not significant. For example, 1,000 may contain from one to four significant digits, but in this book it will be assumed to have one significant digit.
4. If a value has no significant digits to the left of a decimal point, any zeros to the right of the decimal point and also to the left of a significant digit are not significant. For example, 0.0012 has only two significant digits.
5. If a value ends with zeros to the right of a decimal point, those zeros are significant. For example, 0.1200 has four significant digits.

After you have reviewed the rules, use the following table to check your understanding of the rules. Cover up the second column of the table, and try to determine how many significant digits each number in the first column has. If you get confused, refer to the rule given.

Significant Digits		
Measurement	Number of significant digits	Rule
12,345	5	1
2,400 cm	2	3
305 kg	3	2
235.0 cm	4	1 and 5
234.005 K	6	2
12.340	5	5
0.001	1	4
0.002 450	4	4 and 5

Rounding and Significant Digits

When performing mathematical operations with measurements, you must remember to keep track of significant digits. If you are adding or subtracting two measurements, your answer can have only as many decimal positions as the value that has the fewest number of decimal places. When you multiply or divide measurements, your answer can have only as many significant digits as the value that has the fewest number of significant digits.

Practice

1. Determine the number of significant digits in each of the following measurements:
   a. 65.04 mL **c.** 0.007 504 kg
   b. 564.00 m **d.** 1,210 K
2. Perform each of the following calculations, and report your answer with the correct number of significant digits and units:
   a. 0.004 dm + 0.12508 dm =
   b. 340 m ÷ 0.1257 s =
   c. 40.1 m × 0.2453 m =
   d. 1.03 g − 0.0456 g =

   (See the last page of the Skills Handbook for the answers to practice problems.)

SKILLS HANDBOOK Graphing Skills Refresher

Line Graphs

In laboratory experiments, you will usually control one variable and see how it affects another variable. Line graphs can show these relationships clearly. For example, you might perform an experiment in which you measure the volume of a gas at different temperatures to determine how volume is related to temperature. In this experiment, you are controlling the temperature intervals at which the gas's volume is measured. Therefore, temperature is the independent variable. The volume of the gas is the dependent variable. The table below gives some sample data for an experiment that measures the volume of gas.

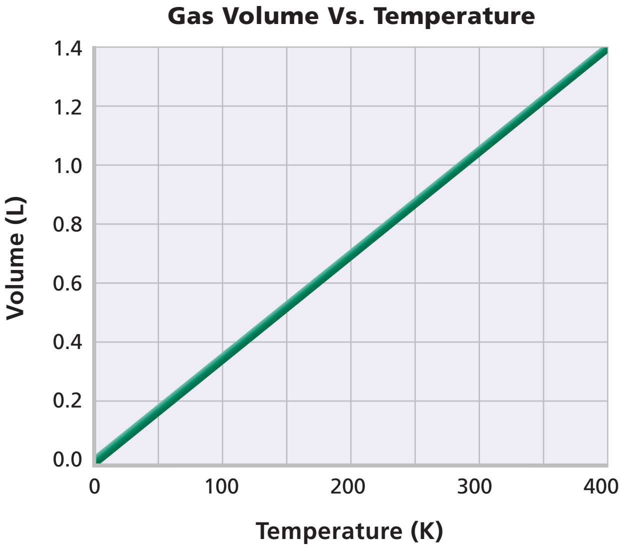
The independent variable is plotted on the *x*-axis. This axis is labeled "Temperature (K)" and has a range from 0 to 400 K. Be sure to properly label each axis, including the units.

The dependent variable is plotted on the *y*-axis. This axis is labeled "Volume (L)" and has a range of 0.0 to 1.4 L.

Experimental Data for Gas Volume Versus Temperature	
Temperature (K)	Gas volume (L)
0	0.0
100	0.35
200	0.70
300	1.05
400	1.4

Think of your graph as a grid that has lines running horizontally from the *y*-axis and vertically from the *x*-axis. To plot a point, find the *x* value on the *x*-axis. For the example above, plot each value for time on the *x*-axis. Follow the vertical line from the *x*-axis until it intersects the horizontal line from the *y*-axis at the corresponding *y* value. For the example, each temperature value has a corresponding volume value. Place your point at the intersection of these two lines.

The line graph below shows how the data in the table may be graphed.



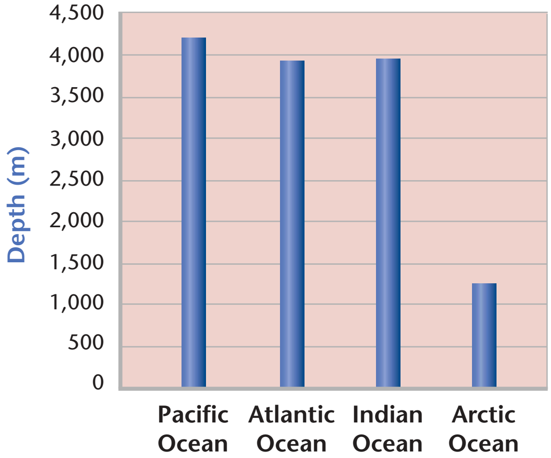
Bar Graphs

Bar graphs are useful for comparing data values. If you wanted to compare the area or depth of the major oceans, you might use a bar graph. The table below gives the data for each of these quantities.

Depth of the Major Oceans	
Ocean	Depth (m)
Pacific Ocean	4,028
Atlantic Ocean	3,926
Indian Ocean	3,963
Arctic Ocean	1,205

To create a bar graph from the data in the table, begin on the *x*-axis by labeling four bar positions with the names of the four oceans. Label the *y*-axis "Depth (m)." Be sure the range on your *y*-axis includes 1,205 m and 4,028 m. Then, draw the bars to represent the area of each ocean.

Make sure the bar height on the *y*-axis matches each ocean's area value, as shown in the bar graph below.



Pie Graphs

Pie graphs can help you visualize how many parts make up a whole. Frequently, pie graphs are made from percentage data. For example, you could create a pie graph that shows the percentage of different materials that make up the waste generated in cities of the United States. Study the example data in the table below.

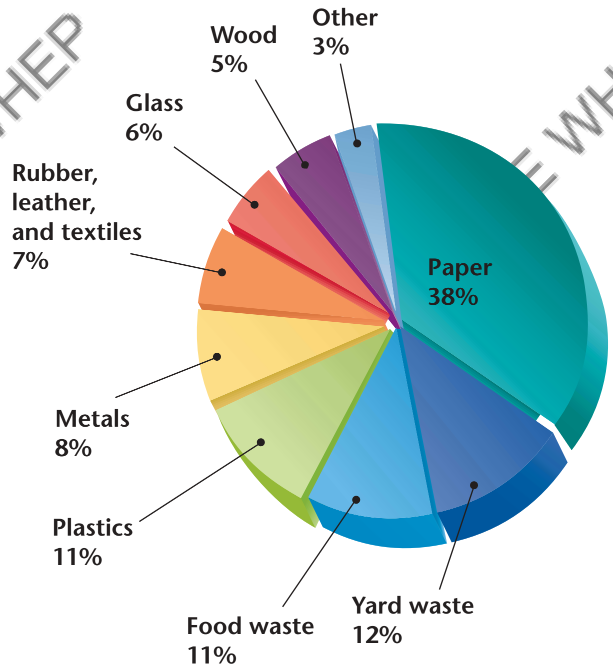
United States Municipal Solid Waste	
Material	Percentage of total waste
Paper	38%
Yard waste	12%
Food waste	11%
Plastics	11%
Metals	8%
Rubber, leather, and textiles	7%
Glass	6%
Wood	5%
Other	3%

To create a pie graph from the data in the table, begin by drawing a circle to represent the whole, or total. Because all circles are 360°, 1% of a circle is equal to 3.6°. From this point, the pie graph can be constructed in two ways.

First, a protractor can be used to measure the number of degrees that are represented by a percentage of the circle. For example, if paper represents 38% of the municipal solid waste in the United States, that percentage would be equal to $38 \times 3.6°$, or 138.6°.

Second, the circle can be divided into 100 equal sections of 3.6° each. Then, you can shade in 38 consecutive sections and label that area "Paper." Continue to shade sections with other colors until the entire pie graph has been filled in and until each type of waste has a corresponding area in the circle, as shown in the pie graph below.

United States Municipal Solid Waste (Percentage by Weight)



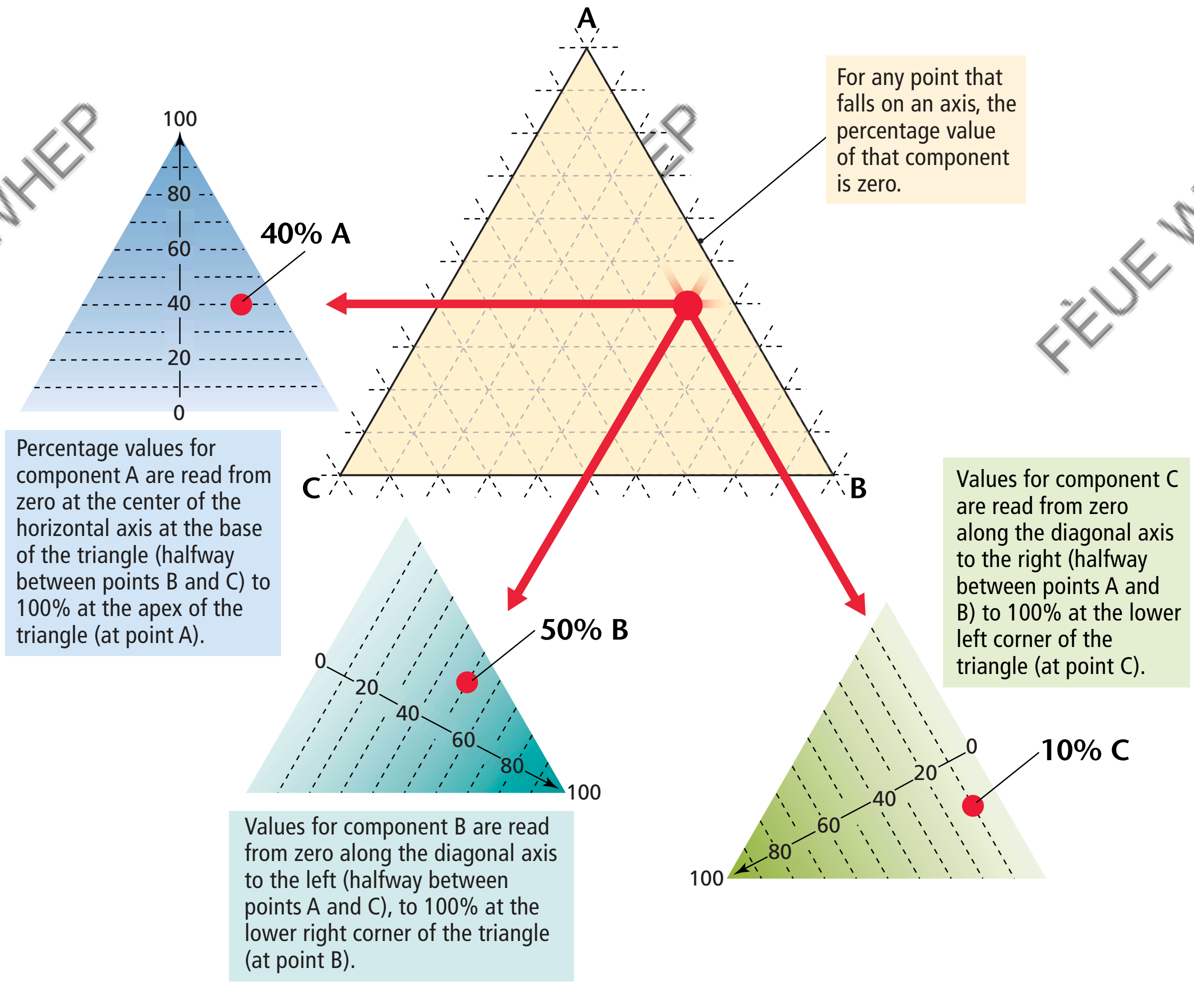
Ternary Diagrams

Ternary graphs, or ternary diagrams, show three variables on the same plot. Earth scientists use ternary diagrams to show composition of rocks and minerals and the physical states of rock material. The most common use of ternary diagrams is to represent the relative percentage of three components, such as three minerals or three elements.

The composition of any point on a ternary diagram can be described by first determining the percentage of each of the three components, as shown in the diagram below. In a ternary diagram, any point represents the relative percentage of three components: A, B, and C. The three components must always add up to 100%. In other words, the total composition of the mineral or rock represented by a given point on a ternary diagram is a combination of A, B, and C, so that x% A + y% B + z% C = 100%.

Readings of composition are stated as % A, % B, and % C. For example, the point in the diagram below has a composition of 40% A, 50% B, and 10% C. In most ternary diagrams, areas of the triangle are given names so that scientists can identify a rock or mineral by its name, rather than by its composition.

How to Read a Ternary Diagram



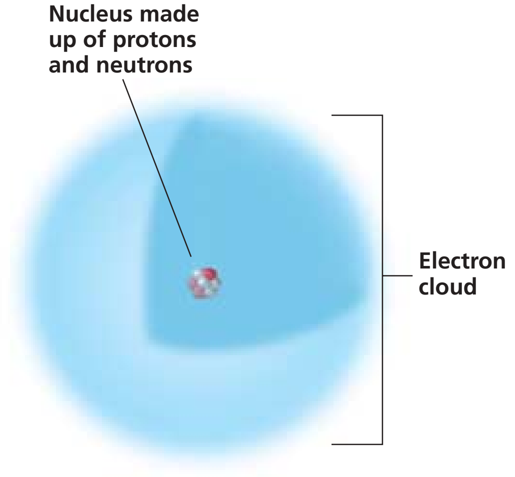
Atoms and Elements

Every object in the universe is made up of particles of matter. Matter is anything that has mass and takes up space. An element is a substance that cannot be separated into simpler substances by chemical means. Elements cannot be separated in this way because each element consists of only one kind of atom. An atom is the smallest unit of an element that maintains the properties of that element.

Atomic Structure Atoms are made up of small particles called *subatomic particles*. The three major types of subatomic particles are **electrons, protons,** and **neutrons.** Electrons have a negative electrical charge, protons have a positive charge, and neutrons have no electrical charge. The protons and neutrons are packed close to one another and form the **nucleus.** The protons give the nucleus a positive charge. The electrons of an atom are located in a region around the nucleus known as an **electron cloud.** The negatively charged electrons are attracted to the positively charged nucleus.

Atomic Number To help in the identification of elements, scientists have assigned an **atomic number** to each kind of atom. The atomic number is equal to the number of protons in the atom. Atoms that have the same number of protons are all of the same element. An uncharged, or electrically neutral, atom has an equal number of protons and electrons. Therefore, the atomic number is also equal to the number of electrons in an uncharged atom. The number of neutrons, however, can vary for a given element. Atoms that have different numbers of neutrons but are of the same element are called **isotopes.**

Periodic Table of the Elements In a periodic table, the elements are arranged in order of increasing atomic number. Each element in the table is found in a separate box. In each horizontal row of the table, each element has one more electron and one more proton than the element to its left. Each row of the table is called a **period.** Changes in chemical properties across a period correspond to changes in the elements' electron arrangements. Each vertical column of the table, known as a **group,** contains elements that have similar properties. The elements in a group have similar chemical properties because they have the same number of electrons in their outer energy level. For example, the elements helium, neon, argon, krypton, xenon, and radon all have similar properties and are known as the *noble gases*.



▶ The nucleus of the atom contains the protons and neutrons. The protons give the nucleus a positive charge. The negatively charged electrons are in the electron cloud surrounding the nucleus.

Molecules and Compounds

When the atoms of two or more elements are joined chemically, the resulting substance is called a **compound.** A compound is a new substance that has properties different from those of the elements that compose it. For example, water, H_2O, is a compound formed when atoms of hydrogen, H, and oxygen, O, combine. The smallest complete unit of a compound that has all of the properties of that compound is called a **molecule.**