Section 20.1

1 FOCUS

Section Objectives

20.1 **Define** air mass.
20.2 **Explain** how air masses are classified.
20.3 **Explain** the characteristic features of each air mass class.
20.4 **Explain** the influence of continental polar and maritime tropical air masses on the majority of North America.

Reading Focus

Build Vocabulary L2

Paraphrase Ask students to write the vocabulary words on a sheet of paper. Instruct students to write a definition, in their own words, for each term as they encounter the term while going through the chapter. After writing their own definition, they should also write a complete sentence using the term.

Reading Strategy L2

a. an immense body of air characterized by similar temperatures and amounts of moisture at any given altitude
b. area over which an air mass gets its characteristic properties of temperature and moisture
c. cold air mass that forms at high latitudes toward Earth's poles
d. warm air mass that forms at low latitudes
e. dry air mass that forms over land
f. humid air mass that forms over water

20.1 Air Masses

Reading Focus

Key Concepts

- What is an air mass?
- What happens as an air mass moves over an area?
- How are air masses classified?
- Which air masses influence much of the weather in North America?
- Why do continental tropical air masses have little effect on weather in North America?

Vocabulary

- air mass

Reading Strategy

Building Vocabulary Copy the table. As you read this section, write a definition for each of the terms in the table. Refer to the table as you read the rest of the chapter.

Term	Definition
Air mass	a. ___?___
Source region	b. ___?___
Polar air mass	c. ___?___
Tropical air mass	d. ___?___
Continental air mass	e. ___?___
Maritime air mass	f. ___?___

Figure 1 Tornado Damage in Kansas The force of the wind during a tornado was strong enough to drive a piece of metal into the utility pole.

Severe storms are among nature's most destructive forces. Every spring, for example, newspapers and newscasts report the damage caused by tornadoes, which are short but violent windstorms that move quickly over land. The forces associated with these storms can be incredibly strong, as you can see from the damage shown in Figure 1. During late summer and early fall, you have probably heard reports about severe storms known as hurricanes. Unlike tornadoes, hurricanes form over Earth's tropical oceans. As they move toward land, the strong winds and heavy rains produced by these storms can destroy anything in their paths. You are probably most familiar with a type of severe storm known as a thunderstorm. Thunderstorms are a type of severe weather that produces heavy rains, loud noises you know as thunder, and flashes of light called lightning. Before learning more about these different types of violent weather, you will learn about the atmospheric conditions that most often affect the day-to-day weather.

558 Chapter 20

Air Masses and Weather

For the many people who live in the middle latitudes, which include much of the United States, summer heat waves and winter cold spells are familiar experiences. During summer heat waves, several days of high temperatures and high humidity often end when a series of storms pass through the area. This stormy weather is followed by a few days of relatively cool weather. By contrast, winter cold spells are often characterized by periods of frigid temperatures under clear skies. These bitter cold periods are usually followed by cloudy, snowy, relatively warm days that seem mild when compared to those just a day earlier. In both of these situations, periods of fairly constant weather conditions are followed by a short period of changes in the weather. What do you think causes these changes?

Air Masses The weather patterns just described result from movements of large bodies of air called air masses. **An air mass is an immense body of air that is characterized by similar temperatures and amounts of moisture at any given altitude.** An air mass can be 1600 kilometers or more across and several kilometers thick. Because of its size, it may take several days for an air mass to move over an area. This causes the area to experience fairly constant weather, a situation often called air-mass weather. Some day-to-day variations may occur, but the events will be very unlike those in an adjacent air mass.

Movement of Air Masses When an air mass moves out of the region over which it formed, it carries its temperature and moisture conditions with it. An example of the influence of a moving air mass is shown in Figure 2. A cold, dry air mass from northern Canada is shown moving southward. The initial temperature of the air mass is −46°C. It warms 13 degrees by the time it reaches Winnipeg. The air mass continues to warm as it moves southward through the Great Plains and into Mexico. Throughout its southward journey, the air mass becomes warmer. But it also brings some of the coldest weather of the winter to the places in its path. **As it moves, the characteristics of an air mass change and so does the weather in the area over which the air mass moves.**

Reading Checkpoint *What is an air mass, and what happens as it moves over an area?*

Figure 2 As a frigid Canadian air mass moves southward, it brings colder weather to the area over which it moves.
Computing *How much warmer was the air mass when it reached Tampico, Mexico, than when it formed?*

2 INSTRUCT

Air Masses and Weather

Teacher Demo

Air Masses in a Bottle L2

Purpose Students will observe what occurs when hot and cold air masses collide.

Materials 2 wide-mouthed jars of the same size, matches, small pan, hot water, ice cubes, flashlight

Procedure Place the hot water in the pan. Place one of the jars in the pan. Using the matches, fill both jars with smoke. Place the second jar on top of the one in the pan. Place the ice cubes on top of the second jar. Darken the classroom and use the flashlight to observe the movement of the smoke within the jars.

Expected Outcomes The hot air will rise in the first jar; the cold air will sink in the second jar
Kinesthetic, Visual

Customize for English Language Learners

Direct students to Figure 3 on p. 560. Before they read, have them use the figure to make a list of the four types of air masses impacting North America. Students should add definitions for the terms to the glossary as they read the section.

Answer to . . .

Figure 2 *56°C warmer*

Reading Checkpoint *An air mass is an immense body of air characterized by similar temperatures and amounts of moisture at any given altitude. As it moves, the characteristics of an air mass change and the weather in the area over which the air mass moves also changes.*

Classifying Air Masses

Use Visuals L1

Figure 3 Direct students' attention to the map in Figure 3. Ask: **What type of air mass influence the weather in the northeast?** *(maritime polar)* **The southeast?** *(maritime tropical)*
Visual

Use Community Resources L2

Invite a meteorologist to speak to the class about the role that air masses play in the weather in North America. Have students ask about the dominant air masses that influence your local area.
Interpersonal

Go Online NSTA SciLinks

Download a worksheet on air masses for students to complete, and find additional teacher support from NSTA SciLinks.

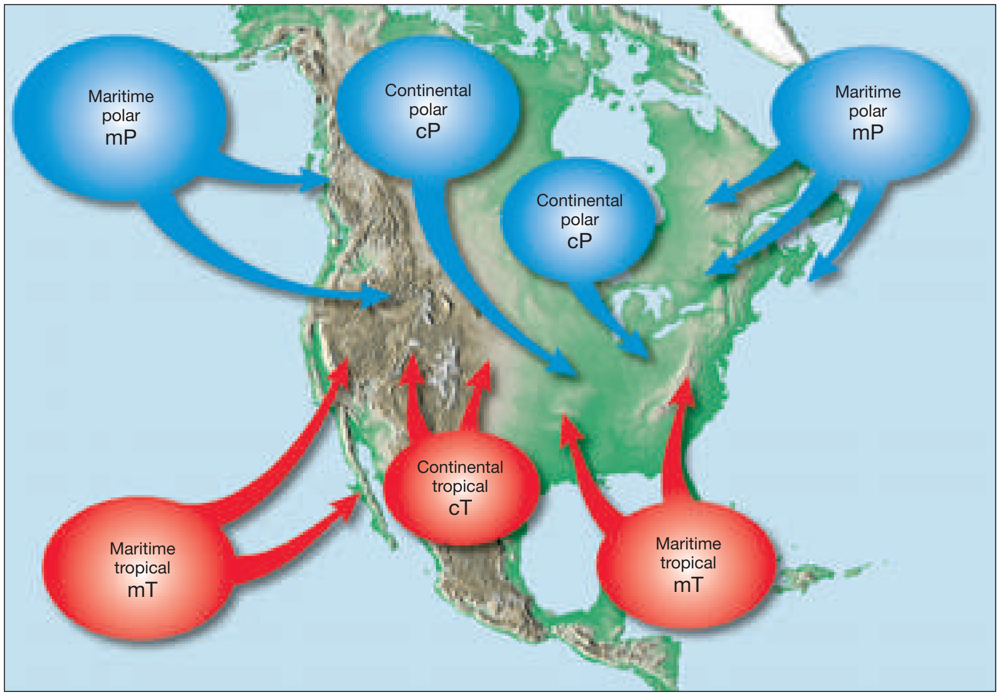


Figure 3 Air masses are classified by the region over which they form. **Interpreting Maps** ***What kinds of air masses influence the weather patterns along the west coast of the United States?***

Classifying Air Masses

The area over which an air mass gets its characteristic properties of temperature and moisture is called its source region. The source regions that produce air masses that influence the weather in North America are shown in Figure 3. Air masses are named according to their source region. Polar (P) air masses form at high latitudes toward Earth's poles. Air masses that form at low latitudes are tropical (T) air masses. The terms *polar* and *tropical* describe the temperature characteristics of an air mass. Polar air masses are cold, while tropical air masses are warm.

In addition to their overall temperature, air masses are classified according to the surface over which they form. Continental (c) air masses form over land. Maritime (m) air masses form over water. The terms *continental* and *maritime* describe the moisture characteristics of the air mass. Continental air masses are likely to be dry. Maritime air masses are humid.

Using this classification scheme, there are four basic types of air masses. A continental polar (cP) air mass is dry and cool. A continental tropical (cT) air mass is dry and warm or hot. Maritime polar (mP) and maritime tropical (mT) air masses both form over water. But a maritime polar air mass is much colder than a maritime tropical air mass.

Go Online NSTA SciLinks

For: Links on air masses
Visit: www.SciLinks.org
Web Code: cjn-6201

Facts and Figures

Maritime polar air originates over cold ocean currents or high-latitude ocean waters. This air does not have as much moisture content as mT air, yet it can produce widespread rain or snow. This air mass is notorious for producing fog, drizzle, cloudy weather, and long-lasting light-to-moderate rain. Maritime polar air changes as it moves over elevated terrain. On the windward side of mountain ranges, mP air can produce an abundance of rain and snow. Once on the lee side of mountains, the mP air mass modifies into a continental air mass. These air masses produce cold fronts, but the air is not as cold as polar or arctic fronts. They are often referred to as "Pacific fronts" or "back-door cold fronts." Maritime polar air occurs frequently in the Pacific Northwest and to a lesser degree in New England.

MAP MASTER Skills Activity

Figure 4

Location Marquette, Michigan, is southeast of Thunder Bay, Ontario.
Identify What type of air mass influences the weather of these two cities?
Infer Which of these cities receives more snow in an average winter? Why?

Weather in North America

Much of the weather in North America, especially weather east of the Rocky Mountains, is influenced by continental polar (cP) and maritime tropical (mT) air masses. The cP air masses begin in northern Canada, the interior of Alaska, and the Arctic areas. The mT air masses most often begin over the warm waters of the Gulf of Mexico, the Caribbean Sea, or the adjacent Atlantic Ocean.

Continental Polar Air Masses Continental polar air masses are uniformly cold and dry in winter and cool and dry in summer. In summer, cP air masses may bring a few days of relatively cooler weather. In winter, this continental polar air brings the clear skies and cold temperatures you associate with a cold wave.

Continental polar air masses are not, as a rule, associated with heavy precipitation. However, those that cross the Great Lakes during late autumn and winter sometimes bring snow to the leeward shores, as shown in Figure 4. These localized storms, which are known as lake-effect snows, make Buffalo and Rochester, New York, among the snowiest cities in the United States. What causes lake-effect snow? During late autumn and early winter, the difference in temperature between the lakes and adjacent land areas can be large. The temperature contrast can be especially great when a very cold cP air mass pushes southward across the lakes. When this occurs, the air gets large quantities of heat and moisture from the relatively warm lake surface. By the time it reaches the opposite shore, the air mass is humid and unstable. Heavy snow, like that shown in Figure 5, is possible.

Reading Checkpoint *What causes large amounts of snow to fall on the southern and eastern shores of the Great Lakes?*

Figure 5 A six-day lake-effect snowstorm in November 1996 dropped a record 175 cm (69 in.) of snow on Chardon, Ohio.

Weather in North America

Build Reading Literacy **L1**

Refer to **p. 334D** in **Chapter 12**, which provides the guidelines for outlining.

Outline Have students read the section. Then, have students use the headings as major divisions in an outline. Allow students to refer to their outlines when answering the questions in Section 20.1 Assessment.
Visual

MAP MASTER Skills Activity

Answers
Identify Continental polar air masses influence the weather in this region.

Infer Because it is on the downwind side of Lake Superior, Marquette receives more snow than Thunder Bay does.

Facts and Figures

On November 20–23, 2000, Buffalo, NY, and the surrounding area were hit with a 60-hour lake-effect snowstorm. During the period, the storm dumped up to 79 cm of snow and was the most widespread and significant November lake-effect storm since 1996, when a longer lasting storm dropped about a meter of snow.

The November 2000 storm had frequent lightning as snow showers grew heavy. Snow fell at the rate of 5–10 cm per hour for several hours. The timing of the most intense snowfall could not have been worse. It hit just before the evening commute. Thousands were reported to have spent the night in their cars or to have taken shelter in stores and hotels. Many schoolchildren and school buses became trapped. It was the most disruptive storm in the Buffalo area since the blizzard of 1977.

Answer to . . .

Figure 3 *maritime polar (mP) and maritime tropical (mT) air masses*

Reading Checkpoint *Continental polar air masses, crossing the Great Lakes, cause heavy lake-effect snows.*

Section 20.1 (continued)

Build Science Skills L2

Using Tables and Graphs Have students create a table to compare and contrast the four basic types of air masses.
Intrapersonal, Verbal

Build Reading Literacy L1

Refer to **p. 124D** in **Chapter 5,** which provides the guidelines for this strategy.

Summarize Have students summarize what they have learned in this section by listing the characteristics of each type of air mass. Ask them to create a two-column chart with the column headings "Air mass type" and "Characteristics." (You may alternatively create a chart on the board to make this an interactive class activity.) Make sure students describe four air masses: cP, cT, mP, and mT.
Portfolio, Group

Use Community Resources L2

Invite students to find out what types of air masses commonly affect their region. Encourage them to consult periodicals at their local library. If their sources do not explicitly mention a specific type of air mass, have them record temperature and precipitation data. Then lead a discussion about what air masses are likely to cause such conditions.
Verbal, Group

Figure 6 Rain Storm over Florida Bay in the Florida Keys

Maritime Tropical Air Masses Maritime tropical air masses also play a dominant role in the weather of North America. These air masses are warm, loaded with moisture, and usually unstable. Maritime tropical air is the source of much, if not most, of the precipitation received in the eastern two thirds of the United States. The heavy precipitation shown in Figure 6 is the result of maritime tropical air masses moving through the area. In summer, when an mT air mass invades the central and eastern United States, it brings the high temperatures and oppressive humidity typically associated with its source region.

Maritime Polar Air Masses During the winter, maritime polar air masses that affect weather in North America come from the North Pacific. Such air masses often begin as cP air masses in Siberia. The cold, dry continental polar air changes into relatively mild, humid, unstable maritime polar air during its long journey across the North Pacific, as shown in Figure 7. As this maritime polar air arrives at the western shore of North America, it is often accompanied by low clouds and showers. When this maritime polar air advances inland against the western mountains, uplift of the air produces heavy rain or snow on the windward slopes of the mountains.

Maritime polar air masses also originate in the North Atlantic off the coast of eastern Canada. These air masses influence the weather of the northeastern United States. In winter, when New England is on the northern or northwestern side of a passing low-pressure center, the counterclockwise winds draw in maritime polar air. The result is a storm characterized by snow and cold temperatures, known locally as a nor'easter.

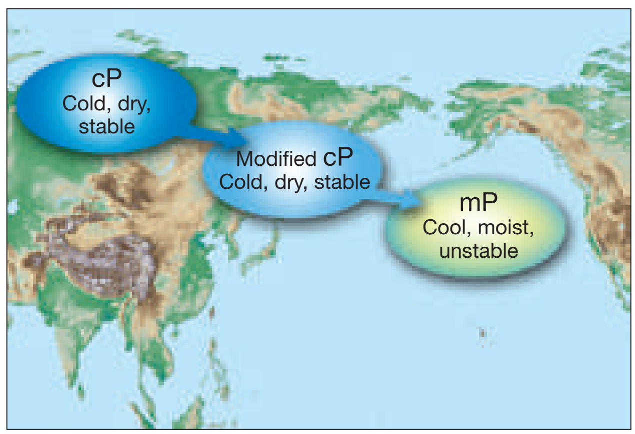


Figure 7 During winter, maritime polar (mP) air masses in the northern Pacific Ocean usually begin as continental polar (cP) air masses in Siberia. **Inferring** ***What happens to the mP air masses as they cross the Pacific?***

Figure 8 A cT air mass produces a few days of warm weather amid the cool days of fall in the Great Lakes region.

Continental Tropical Air Masses Continental tropical air masses have the least influence on the weather of North America. These hot, dry air masses begin in the southwestern United States and Mexico during the summer. **Only occasionally do cT air masses affect the weather outside their source regions.** However, when a cT air mass does move from its source region, it can cause extremely hot, droughtlike conditions in the Great Plains in the summer. Movement of such air masses in the fall results in mild weather in the Great Lakes region, often called Indian summer. Conditions during Indian summer are unseasonably warm and mild, as shown in Figure 8.

Section 20.1 Assessment

Reviewing Concepts

1. What is an air mass?
2. What happens as an air mass moves over an area?
3. How are air masses classified?
4. Which types of air masses have the greatest effect on weather in North America?
5. Why do continental tropical air masses have little effect on weather in North America?

Critical Thinking

6. **Comparing and Contrasting** Compare and contrast the four types of air masses.
7. **Explaining** Explain which type of air mass could offer relief from a scorching summer to the Midwestern United States. Justify your choice.
8. **Applying Concepts** How can continental polar air be responsible for lake-effect snowstorms in the Great Lakes region?
9. **Identifying** Look again at Figure 3. What kinds of air masses influence the weather patterns over Florida?
10. **Synthesizing** What kind of weather could be expected in southern Canada if an mT air mass was to invade the region in mid-July?

Writing in Science

Explanatory Paragraph Pick one of the air masses shown in Figure 3 that affects the weather in your area. Write a paragraph that explains the weather typically associated with the air mass in both the summer and the winter.

3 ASSESS

Evaluate Understanding

L2

Have each student write a paragraph explaining the term *air-mass weather.* *(Answers should include the fact that weather is a result of moving air masses. Because air masses are so huge it usually takes several days for them to move over an area. This causes fairly constant weather, known as* air mass weather.*)*

Reteach

L1

Use Figure 3 to review the classification of air masses.

Writing in Science

Answers will depend on students' choices of air masses. Continental polar air masses bring clear skies and cold temperatures in winter and relatively cool, dry days in summer. Maritime tropical air masses bring high temperatures and much humidity in summer and much precipitation year round. Continental tropical air masses affect only the southwestern United States and result in dry, warm weather in their source region. Maritime polar masses often bring low clouds and showers in summer and snow and cold temperatures in winter.

Answer to . . .

Figure 7 *The cP air mass acquires moisture as it slowly moves over the ocean to become an mP air mass.*

Section 20.1 Assessment

1. An air mass is an immense body of air characterized by similar temperatures and amounts of moisture at any given altitude.
2. The air mass changes the weather in the area over which it moves.
3. Air masses are classified by temperature (polar or tropical) and the surface (continental or maritime) over which they form.
4. continental polar and maritime tropical air masses
5. Such air masses rarely move from their source regions.
6. They are similar in that each influences weather in North America. They differ in that continental air masses form over land and thus are dry. Maritime air masses form over water and thus are wet. Polar air masses are cold, while tropical air masses are warm.
7. A continental polar (cP) air mass is cool and dry and is usually associated with high pressure and clear skies. Such an air mass would offer relief from hot summer weather.
8. Although cP air masses are cold and dry, they acquire moisture as they cross the relatively warm lakes. The addition of moisture and the increase in temperature make the air masses unstable, causing snow to fall downwind of the lakes.
9. maritime tropical
10. Oppressively hot and humid weather typical of the source region of the air mass would occur in southern Canada.

1 FOCUS

Section Objectives

20.5 **Describe** the formation of a front.

20.6 **Differentiate** among the formation of a warm front, cold front, stationary front, and occluded front.

20.7 **Describe** the weather patterns associated with each type of front.

Reading Focus

Build Vocabulary L2

Web Diagram Have students construct a web diagram of the vocabulary words in this section. The main concept (fronts) should be at the top of the diagram. Ask students to provide one descriptive statement for each of the other vocabulary words.

Reading Strategy L2

I. A. warm air moves into an area formerly covered by cooler air
   B. light-to-moderate precipitation over wide area for extended time
II. A. cold air moves into region occupied by warmer air
   B. heavy downpours and winds followed by drop in temperature
III. Stationary front
   A. flow of air parallel along front
   B. gentle-to-moderate precipitation
IV. Occluded front
   A. an active cold front overtakes an active warm front
   B. light precipitation

2 INSTRUCT

Formation of Fronts

Use Visuals L1

Figure 9 Direct students' attention to the photograph in the figure. Ask: **What type of precipitation is falling?** *(a light rain)* **What do you know about the general weather conditions in this area based on the photograph?** *(The temperature is above freezing.)* **Visual**

20.2 Fronts

Reading Focus

Key Concepts

- What happens when two air masses meet?
- How is a warm front produced?
- What is a cold front?
- What is a stationary front?
- What are the stages in the formation of an occluded front?
- What is a middle-latitude cyclone?
- What fuels a middle-latitude cyclone?

Vocabulary

- front
- warm front
- cold front
- stationary front
- occluded front

Reading Strategy

Outlining As you read, make an outline like the one below. Include information about how each of the weather fronts discussed in this section forms and the weather associated with each.

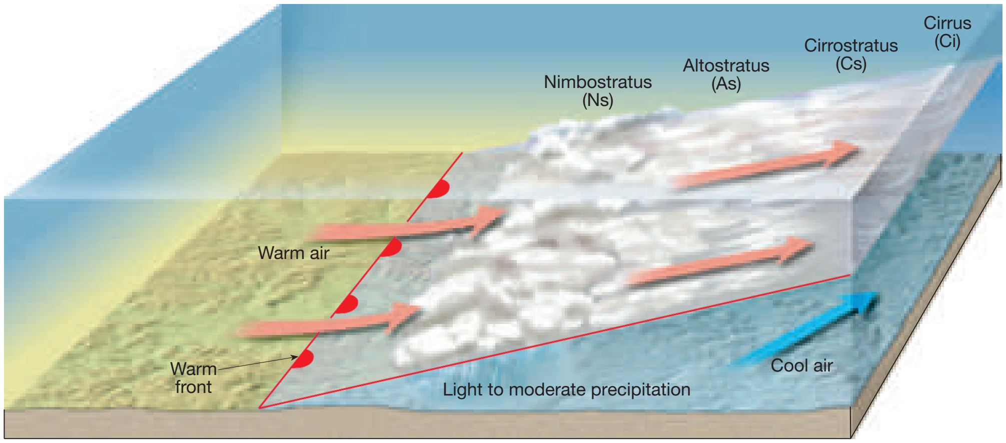
Fronts
I. Warm front
A. ____?____
B. ____?____
II. Cold front
A. ____?____
B. ____?____

Formation of Fronts

Recall that air masses have different temperatures and amounts of moisture, depending on their source regions. Recall also that these properties can change as an air mass moves over a region. What do you think happens when two air masses meet? **When two air masses meet, they form a front, which is a boundary that separates two air masses.** Fronts can form between any two contrasting air masses. Fronts are often associated with some form of precipitation, such as that shown in Figure 9.

Figure 9 Precipitation from a Storm in South Africa

In contrast to the vast sizes of air masses, fronts are narrow. Most weather fronts are between about 15 and 200 km wide. Above Earth's surface, the frontal surface slopes at a low angle so that warmer, less dense air overlies cooler, denser air. In the ideal case, the air masses on both sides of a front move in the same direction and at the same speed. When this happens, the front acts simply as a barrier that travels with the air masses. In most cases, however, the distribution of pressure across a front causes one air mass to move faster than the other. When this happens, one air mass advances into another, and some mixing of air occurs.



Types of Fronts

Fronts are often classified according to the temperature of the advancing front. There are four types of fronts: warm fronts, cold fronts, stationary fronts, and occluded fronts.

Warm Fronts

A warm front forms when warm air moves into an area formerly covered by cooler air. On a weather map, the surface position of a warm front is shown by a red line with red semicircles that point toward the cooler air.

The slope of the warm front is very gradual, as shown in Figure 10. As warm air rises, it cools to produce clouds, and frequently precipitation. The sequence of clouds shown in Figure 10 typically comes before a warm front. The first sign of the approaching warm front is the appearance of cirrus clouds. As the front nears, cirrus clouds change into cirrostratus clouds, which blend into denser sheets of altostratus clouds. About 300 kilometers ahead of the front, thicker stratus and nimbostratus clouds appear, and rain or snow begins.

Because of their slow rate of movement and very low slope, warm fronts usually produce light-to-moderate precipitation over a large area for an extended period. A gradual increase in temperature occurs with the passage of a warm front. The increase is most apparent when a large temperature difference exists between adjacent air masses. Also, a wind shift from the east to the southwest is associated with a warm front.

Reading Checkpoint *What causes a warm front to form?*

Figure 10 Formation of a Warm Front A warm front forms when warm air glides up over a cold, dense air mass. The affected area has warmer temperatures, and light to moderate precipitation.

Types of Fronts

Use Visuals

L1

Figure 10 Have students examine the diagram of a warm front in the figure. Ask: **As a warm front approaches, what type of weather can you expect?** *(rainy weather)* **Describe how the sky conditions change as a warm front approaches.** *(It becomes increasingly cloudy.)*
Visual

Build Science Skills

L2

Applying Concepts Students will process and remember information about fronts if they can connect this information to their daily experiences. First, gather and display current weather maps. (Many national newspapers have maps that show notable air masses and fronts. Online resources, such as accuweather.com, also have current national and regional weather maps.) Next, ask students to describe local weather conditions. Then discuss how their observations relate to the data presented in the maps.
Verbal, Visual

Customize for English Language Learners

Students who are learning English can benefit from real-life examples that relate to science content. Encourage students to think of observations they have made about the weather. For example, ask students if they notice that after a severe, rather fast-moving thunderstorm, things become cooler the next few days. Explain this is because a cold front moved into the area, bringing thunderstorms and cooler weather.

Answer to . . .

Reading Checkpoint *When warm air moves into an area formerly covered by cooler air, a warm front forms.*

Build Science Skills

L2

Using Models Provide students with red and blue clay. The red clay will represent a warm air mass, and the blue clay will represent a colder air mass. Ask students to use the clay to model one of the four air masses discussed in the text. They should then present their model to the class, explaining the motion of each air mass.
Kinesthetic, Interpersonal

ACTIVITY

Address Misconceptions

L2

Students may think that the terms *warm front* and *cold front* are actually referring to masses of warm air and cold air. It is important that they realize that warm and cold are comparative terms. For example, a warm front may pass though Iowa in the middle of February. This warm air mass may have a temperature of −26°C when the air mass already in place has a temperature of −32°C. Death Valley in the middle of July may have a cold front move through that brings temperatures of 46°C, while the air in place may have a temperature of 49°C. Emphasize to students that a warm front brings warmer air to an area and a cold front brings cooler air.
Verbal

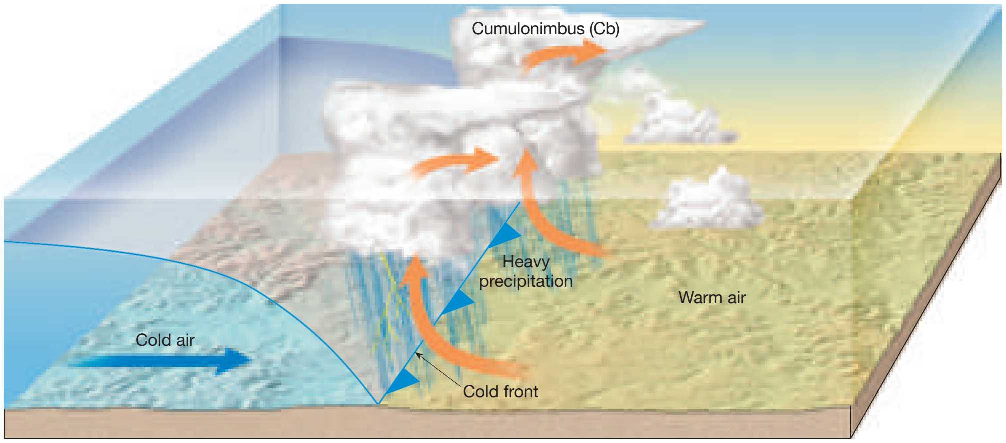


Figure 11 Formation of a Cold Front A cold front forms when cold air moves into an area occupied by warmer air. The affected area experiences thunderstorms if the warm air is unstable.

Cold Fronts

A cold front forms when cold, dense air moves into a region occupied by warmer air. On a weather map, the surface position of a cold front is shown by a blue line edged with blue triangles that point toward the warmer air mass.

Figure 11 shows how a cold front develops. As this cold front moves, it becomes steeper. On average, cold fronts are about twice as steep as warm fronts and advance more rapidly than warm fronts do. These two differences—rate of movement and steepness of slope—account for the more violent weather associated with a cold front.

The forceful lifting of air along a cold front can lead to heavy downpours and gusty winds. As a cold front approaches, towering clouds often can be seen in the distance. Once the cold front has passed, temperatures drop and wind shifts. The weather behind a cold front is dominated by a cold air mass. So, weather clears soon after a cold front passes. When a cold front moves over a warm area, low cumulus or stratocumulus clouds may form behind the front.

Stationary Fronts

Occasionally, the flow of air on either side of a front is neither toward the cold air mass nor toward the warm air mass, but almost parallel to the line of the front. **In such cases, the surface position of the front does not move, and a stationary front forms.** On a weather map, stationary fronts are shown by blue triangles on one side of the front and red semicircles on the other. Sometimes, gentle to moderate precipitation occurs along a stationary front.

Reading Checkpoint *How are cold fronts different from warm fronts?*

Occluded Fronts **When an active cold front overtakes a warm front, an occluded front forms.** As you can see in Figure 12, an occluded front develops as the advancing cold air wedges the warm front upward. The weather associated with an occluded front is generally complex. Most precipitation is associated with the warm air's being forced upward. When conditions are suitable, however, the newly formed front is capable of making light precipitation of its own.

It is important to note that the descriptions of weather associated with fronts are general descriptions. The weather along any individual front may or may not conform to the idealized descriptions you've read about. Fronts, like all aspects of nature, do not always behave as we would expect.

Middle-Latitude Cyclones

Now that you know about air masses and what happens when they meet, you're ready to apply this information to understanding weather patterns in the United States. The main weather producers in the country are middle-latitude cyclones. On weather maps, these low-pressure areas are shown by the letter L.

Middle-latitude cyclones are large centers of low pressure that generally travel from west to east and cause stormy weather. The air in these weather systems moves in a counterclockwise direction and in toward the center of the low. Most middle-latitude cyclones have a cold front, and frequently a warm front, extending from the central area. Forceful lifting causes the formation of clouds that drop abundant precipitation.

How do cyclones develop and form? The first stage is the development of a front, which is shown in Figure 14A on page 569. The front forms as two air masses with different temperatures move in opposite directions. Over time, the front takes on a wave shape, as shown in Figure 14B. The wave is usually hundreds of kilometers long.

Formation of an Occluded Front

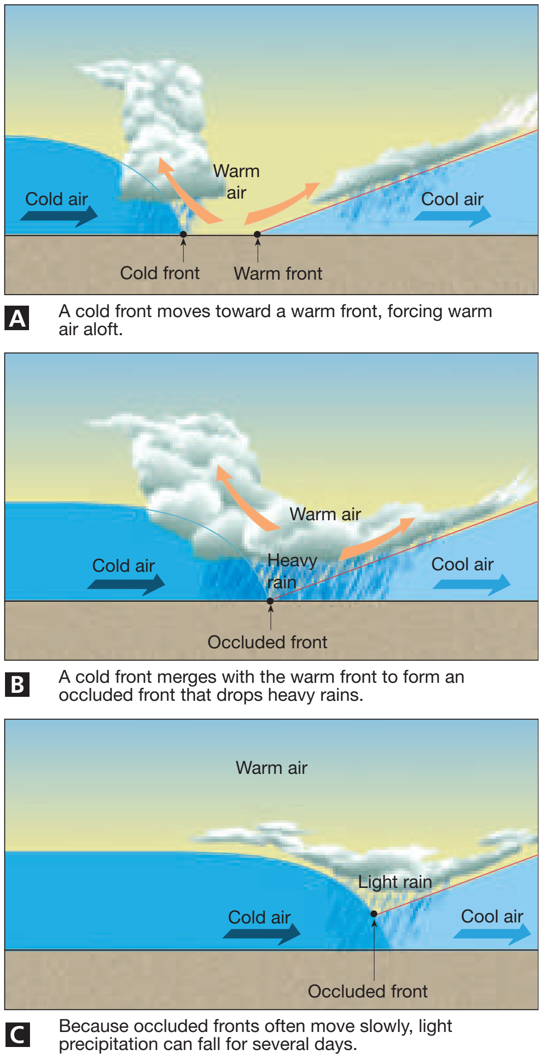


Figure 12 An occluded front forms when a cold front overtakes a warm front, producing a complex weather pattern.

Middle-Latitude Cyclones

Build Reading Literacy

L1

Refer to **p. 556D,** which provides the guidelines for active comprehension.

Active Comprehension Instruct students to read the first two paragraphs of Middle-Latitude Cyclones on p. 567. Ask: **What more would you like to know about middle-latitude cyclones** or **Where does the weather in your area come from?** You will need to make connections for students between the weather and their lives. For example, students may notice from weather reports on television or on the Internet that stormy weather seems to move from the west to the east. Write down several students' responses on the board. Have students continue reading the section and examine Figure 14 on p. 569. While reading, have students consider the questions they had about the material. Have students discuss the section content, making sure that each question raised at the beginning is answered or that students know where to look for the answer.
Verbal

Facts and Figures

One-Eyed Storms Have students consider the word *Cyclops*. These giants of Greek mythology had a single eye in the middle of their foreheads. This word comes from the Greek word *Kyklōps*, which means "round-eyed." The word *cyclone* has a similar meaning. It comes from the Greek word *kykloein*, which means "to circle around." Students can think of cyclones as one-eyed monsters.

Answer to . . .

Reading Checkpoint *Cold fronts are much steeper than warm fronts and advance more rapidly than warm fronts do, causing more violent weather to form.*

Weather Patterns and Severe Storms 567

Section 20.2 (continued)

Teacher Demo

Getting to the Point of Fronts **L2**

Purpose Students will observe the motion of mid-latitude cyclones.

Materials pencil

Procedure This activity may be performed as a demonstration or each student can participate individually. Place a pencil between your hands. Explain that your hands represent two different air masses and the gap between them is the front. Slowly move your right hand forward and your left hand backward. This models the movement of the wind in a stationary front. Direct students' attention to the movement of the pencil.

Expected Outcome The pencil should move in a counterclockwise direction. This models the movement of a mid-latitude cyclone.
Kinesthetic, Visual

Build Reading Literacy **L1**

Refer to **p. 186D** in **Chapter 7,** which provides the guidelines for this strategy.

Relate Text and Visuals The text describes Figure 13 as a "mature cyclone." Ask students to describe what has happened to form this mature cyclone. *(A cold front has overtaken and lifted up a warm front to form an occluded front.)* Now ask students to compare Figures 13 and 14. Ask: **Which phase of Figure 14 is most representative of Figure 13?** *(Both D and E are acceptable answers, although the occluded front in Figure 13 seems to be well-developed, making E the better answer.)* Ask: **What weather conditions would this phase of a cyclone produce?** *(high wind speeds and heavy precipitation)*
Verbal, Visual

As the wave develops, warm air moves towards Earth's poles. There it invades the area formerly occupied by colder air. Meanwhile, cold air moves toward the equator. This change in airflow near the surface is accompanied by a change in pressure. The result is airflow in a counterclockwise direction, as Figure 14C shows.

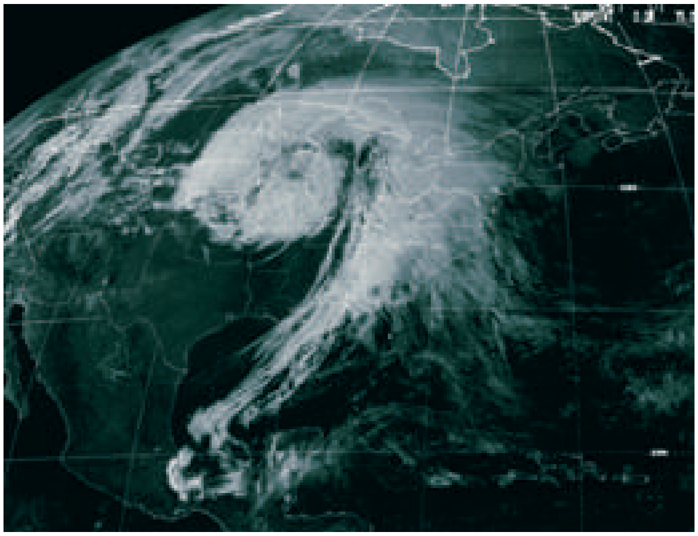


Figure 13 This is a satellite view of a mature cyclone over the eastern United States.

Recall that a cold front advances faster than a warm front. When this occurs in the development of a middle-latitude cyclone, the cold front closes in and eventually lifts the warm front, as Figure 14D shows. This process, which is known as occlusion, forms the occluded front shown in Figure 14E. As occlusion begins, the storm often gets stronger. Pressure at the storm's center falls, and wind speeds increase. In the winter, heavy snowfalls and blizzard-like conditions are possible during this phase of the storm's evolution. A satellite view of this phase of a mature cyclone is shown in Figure 13.

As more of the warm air is forced to rise, the amount of pressure change weakens. In a day or two, the entire warm area is displaced. Only cold air surrounds the cyclone at low levels. The horizontal temperature difference that existed between the two air masses is gone. At this point, the cyclone has exhausted its source of energy. Friction slows the airflow near the surface, and the once highly organized counterclockwise flow ceases to exist (Figure 14F).

The Role of Airflow Aloft

Airflow aloft plays an important role in maintaining cyclonic and anticyclonic circulation. In fact, these rotating surface wind systems are actually generated by upper-level flow.

Cyclones often exist for a week or longer. For this to happen, surface convergence must be offset by outflow somewhere higher in the atmosphere. As long as the spreading out of air high up is equal to or greater than the surface inflow, the low-pressure system can be sustained. **More often than not, air high up in the atmosphere fuels a middle-latitude cyclone.**

Reading Checkpoint ***How do middle-latitude cyclones form and develop?***

Middle-Latitude Cyclone Model

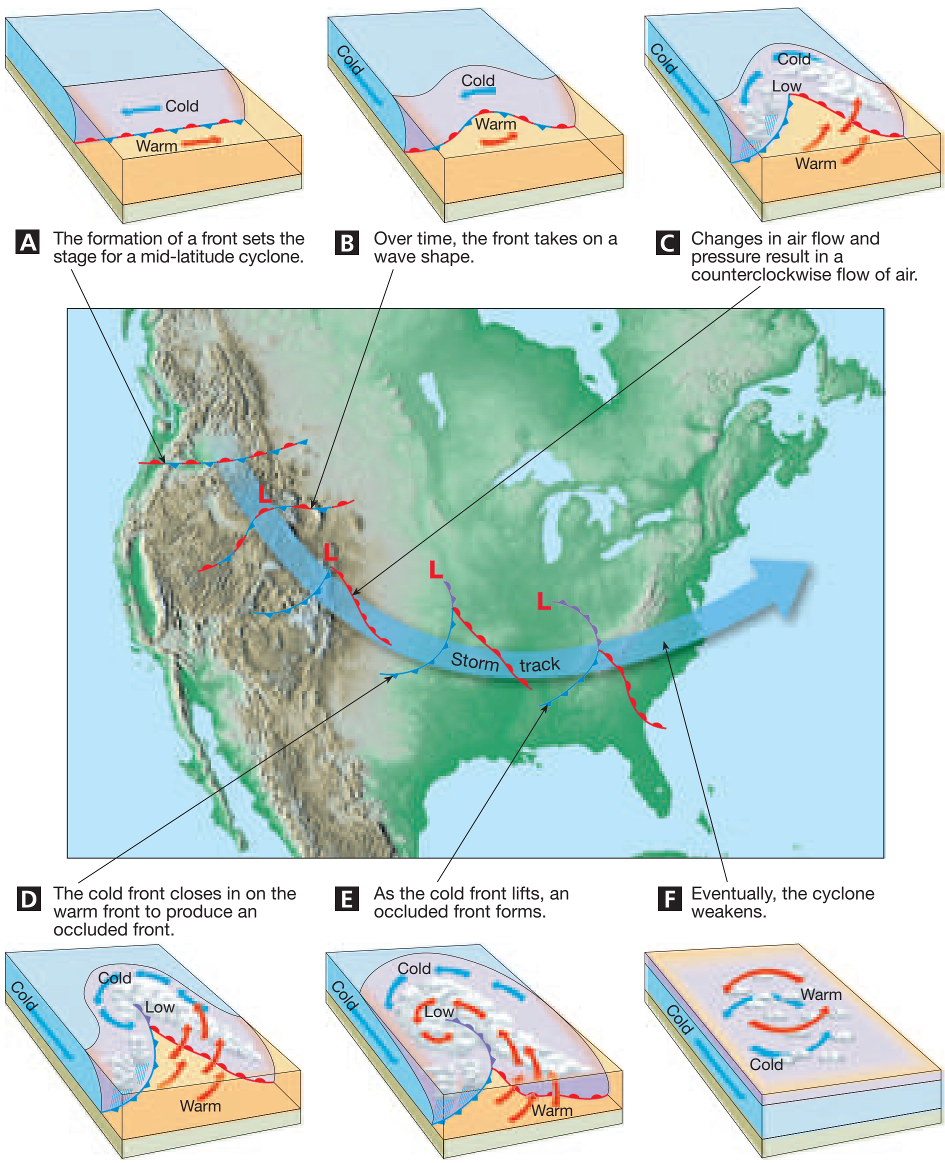


Figure 14 Cyclones have a fairly predictable life cycle.

The Role of Airflow Aloft

Use Visuals **L1**

Figure 14 Instruct students to study the details of the cyclone in the figure. Ask: **In what direction is the air moving in this cyclone?** *(counterclockwise)*
Visual

Integrate Language Arts **L2**

Cyclones Ask students to study Figure 14. The development of a middle-latitude cyclone is complex. Engage students in a discussion about the complexity of this diagram. So much information is conveyed here that often students may feel that they have not gathered all the information they need from it. Challenge them to write a descriptive narrative, explaining the formation of a middle-latitude cyclone in their own words. Students should share their narratives with small groups to make sure that all the steps have been covered.
Verbal, Interpersonal

Answer to . . .

Reading Checkpoint *The first stage is the development of a front. Over time, the front takes on a wave shape. Changes in air flow and pressure result in a counterclockwise flow of air. The cold front eventually closes in on the warm front to produce an occluded front. As the cold front lifts, an occluded front forms. Eventually, the cyclone weakens.*

Section 20.2 (continued)

3 ASSESS

Evaluate Understanding

L2

Have each student write a paragraph explaining the relationship between fronts and precipitation. *(Answers will vary, but students should mention that precipitation is often associated with fronts.)*

Reteach

L1

Review the fact that the main weather producers in the United States are middle-latitude cyclones. Use Figure 14 as a visual aid to discuss how middle-latitude cyclones work.

Writing in Science

An occluded front forms in the late stage of development of a middle-latitude cyclone as fast-moving cold air catches up to a warm front. The warmer air then is forced aloft and eventually dissipates. When this warmer air is gone, there is little condensation and therefore little precipitation.

Answer to . . .

Figure 15 *Both result from changes in surface pressure. Both systems depend on the flow of air high in the atmosphere to maintain their circulation. Cyclones are fueled by upward air movement and reduced surface pressure. Anticyclones form as the result of the downward movement of air and increased surface pressure.*

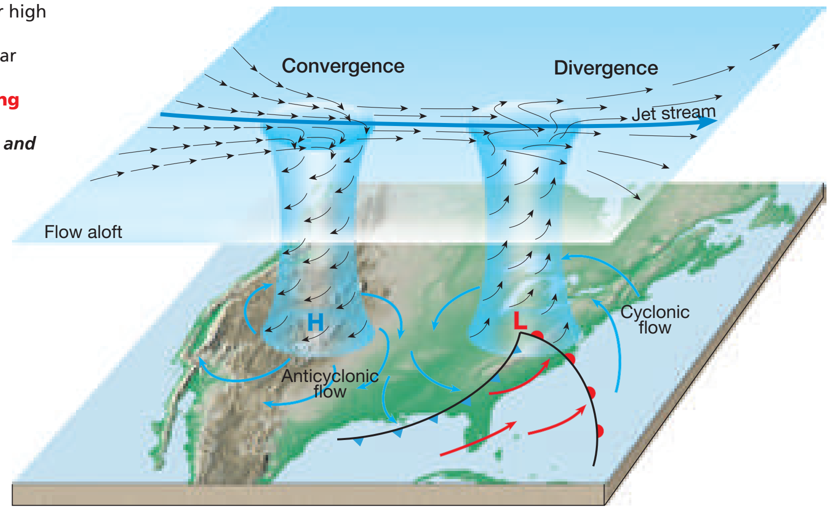


Figure 15 Movements of air high in the atmosphere fuel the cyclones and anticyclones near Earth's surface.
Comparing and Contrasting ***Compare and contrast the movement of air in cyclones and anticyclones.***

Because cyclones bring stormy weather, they have received far more attention than anticyclones. However, a close relationship exists between these two pressure systems. As shown in Figure 15, the surface air that feeds a cyclone generally originates as air flowing out of an anticyclone. As a result, cyclones and anticyclones typically are found next to each other. Like a cyclone, an anticyclone depends on the flow of air high in the atmosphere to maintain its circulation. In an anticyclone, air spreading out at the surface is balanced by air coming together from high up.

Section 20.2 Assessment

Reviewing Concepts

1. What happens when two air masses meet?
2. How does a warm front form?
3. What is a cold front?
4. What is a stationary front?
5. What are the stages in the formation of an occluded front?
6. What is a middle-latitude cyclone?
7. What causes a middle-latitude cyclone to sustain itself?

Critical Thinking

8. **Comparing and Contrasting** Compare and contrast warm fronts and cold fronts.
9. **Synthesizing** Use Figure 15 and what you know about Earth's atmosphere to describe the air movement and pressure conditions associated with both cyclones and anticyclones.

Writing in Science

Explanatory Paragraph Write a paragraph to explain this statement: The formation of an occluded front marks the beginning of the end of a middle-latitude cyclone.

Section 20.2 Assessment

1. When two air masses meet, they form a front, which is a boundary that separates two air masses.
2. A warm front forms when warmer air moves into an area formerly covered by cooler air.
3. A cold front forms when colder, denser air moves into a region occupied by warmer air.
4. Occasionally, the flow of air on either side of a front is neither toward the cold air mass nor toward the warm air mass, but almost parallel to the line of the front. The surface position of the front does not move, and a stationary front forms.
5. A cold front moves toward a warm front, forcing warmer air aloft. The cold front merges with the warm front to form an occluded front that drops heavy rains. The heavy rains are followed by periods of light precipitation.
6. A middle-latitude cyclone is a large center of low pressure that generally travels from west to east in the United States and causes stormy weather.
7. Airflow aloft plays an important role in sustaining a middle-latitude cyclone.
8. Both fronts form when two air masses meet. Warm fronts form when warmer air moves into a region formerly occupied by cold air. Cold fronts form when colder air actively moves into a region occupied by warmer air. Warm fronts move more slowly than cold fronts and have more gradual slopes than cold fronts have.
9. Cyclones are fueled by upward air movement and reduced surface pressure. Anticyclones form as the result of the downward movement of air and increased surface pressure.

20.3 Severe Storms

Reading Focus

Key Concepts
- What is a thunderstorm?
- What causes a thunderstorm to form?
- What is a tornado?
- How does a tornado form?
- What is a hurricane?
- How does a hurricane form?

Vocabulary
- thunderstorm
- tornado
- hurricane
- eye wall
- eye
- storm surge

Reading Strategy
Identifying Cause and Effect Copy the table and complete it as you read this section.

Severe Storms		
	Causes	Effects
Thunderstorms	a. ___?___	b. ___?___
Tornadoes	c. ___?___	d. ___?___
Hurricanes	e. ___?___	f. ___?___

Severe weather has a fascination that everyday weather does not provide. For example, a thunderstorm with its jagged lightning and booming thunder can be an awesome sight. The damage and destruction caused by these storms, as well as other severe weather, can also be frightening. A single severe storm can cause billions of dollars in property damage as well as many deaths. This section discusses three types of severe storms and their causes.

Thunderstorms

Have you ever seen a small whirlwind carry dust or leaves upward on a hot day? Have you observed a bird glide effortlessly skyward on an invisible updraft of hot air? If so, you have observed the effects of the vertical movements of relatively warm, unstable air. These examples are caused by a similar thermal instability that occurs during the development of a thunderstorm. **A thunderstorm is a storm that generates lightning and thunder. Thunderstorms frequently produce gusty winds, heavy rain, and hail.** A thunderstorm may be produced by a single cumulonimbus cloud and influence only a small area. Or it may be associated with clusters of cumulonimbus clouds that stretch for kilometers along a cold front.

Figure 16 Lightning is a spectacular and potentially dangerous feature of a thunderstorm.

Section 20.3

1 FOCUS

Section Objectives
20.8 **Explain** the formation of a thunderstorm.
20.9 **Describe** the conditions needed for a tornado to form.
20.10 **Identify** the conditions that must exist for a hurricane to form.

Reading Focus

Build Vocabulary L2
Venn Diagram Have students create a Venn diagram of hurricanes and tornadoes.

Reading Strategy L2
a. warm, humid air rising in an unstable environment
b. gusty winds, heavy rain, hail
c. associated with thunderstorms and the development of a mesocyclone
d. violent windstorm, isolated path
e. water temperatures warm enough to provide heat and moisture to air
f. widespread damage as winds can reach 300 km/h

2 INSTRUCT

Thunderstorms
Use Visuals L1

Figure 16 Ask students to look at the photograph in Figure 16. Ask: **What type of clouds is probably in the area in this photograph?** *(cumulonimbus clouds)*
Visual

Weather Patterns and Severe Storms 571

Address Misconceptions L2

Students may have heard or noticed in media photographs that many tornadoes seem to hit trailer parks. It may even seem that trailers attract tornadoes. In reality, there are possibly hundreds of very small tornadoes that touch down in the United States every year, but are not recorded because they do no damage. However, since a trailer flips over so easily in even the weakest tornado, trailers probably act as "mini tornado detectors." This makes it seem like tornadoes are attracted to trailers, but that is because trailers are some of the only things that reveal the presence of what would otherwise be an unrecorded event.
Logical

Stages in the Development of a Thunderstorm

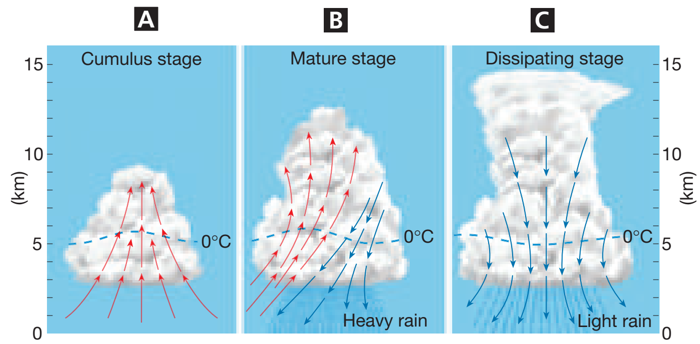


Figure 17 **A** During the cumulus stage, warm, moist air is supplied to the cloud. **B** Heavy precipitation falls during the mature stage. **C** The cloud begins to evaporate during the dissipating stage. **Observing** ***How do the clouds involved in the development of a thunderstorm vary?***

Occurrence of Thunderstorms How common are thunderstorms? Consider these numbers. At any given time, there are an estimated 2000 thunderstorms in progress on Earth. As you might expect, the greatest number occurs in the tropics where warmth, plentiful moisture, and instability are common atmospheric conditions. About 45,000 thunderstorms take place each day. More than 16 million occur annually around the world. The United States experiences about 100,000 thunderstorms each year, most frequently in Florida and the eastern Gulf Coast region. Most parts of the country have from 30 to 100 storms each year. The western margin of the United States has little thunderstorm activity because warm, moist, unstable maritime tropical air seldom penetrates this region.

Development of Thunderstorms **Thunderstorms form when warm, humid air rises in an unstable environment.** The development of a thunderstorm generally involves three stages. During the cumulus stage, shown in Figure 17A, strong updrafts, or upward movements of air, supply moist air. Each new surge of warm air rises higher than the last and causes the cloud to grow vertically.

Usually within an hour of the initial updraft, the mature stage begins, as shown in Figure 17B. At this point in the development of the thunderstorm, the amount and size of the precipitation is too great for the updrafts to support. So, heavy precipitation is released from the cloud. The mature stage is the most active stage of a thunderstorm. Gusty winds, lightning, heavy precipitation, and sometimes hail are produced during this stage.

Eventually, downdrafts, or downward movements of air, dominate throughout the cloud, as shown in Figure 17C. This final stage is called the dissipating stage. During this stage, the cooling effect of the falling precipitation and the flowing in of colder air from high above cause the storm to die down.

The life span of a single cumulonimbus cell within a thunderstorm is only about an hour or two. As the storm moves, however, fresh supplies of warm, humid air generate new cells to replace those that are scattering.

Reading Checkpoint ***Describe the stages in the development of a thunderstorm.***

Customize for Inclusion Students

Behaviorally Disordered Have students work in pairs and use index cards to create a set of flashcards. Students can use the cards to support each other in small study groups. Each card should contain information about a characteristic of one of the three types of storms in this section. One side of the card should contain the term *thunderstorm*, *tornado*, or *hurricane*. The other side should have some fact about the formation of each storm, some factors contributing to each storm, or damage done by each storm.

Tornadoes

Tornadoes are violent windstorms that take the form of a rotating column of air called a vortex. The vortex extends downward from a cumulonimbus cloud. Some tornadoes consist of a single vortex. But within many stronger tornadoes, smaller vortexes rotate within the main funnel. These smaller vortexes have diameters of only about 10 meters and rotate very rapidly. Smaller vortexes explain occasional observations of tornado damage in which one building is totally destroyed, while another one, just 10 or 20 meters away, suffers little damage.

Occurrence and Development of Tornadoes In the United States, about 770 tornadoes are reported each year. These severe storms can occur at any time during the year. However, the frequency of tornadoes is greatest from April through June. In December and January, tornadoes are far less frequent.

Most tornadoes form in association with severe thunderstorms. An important process in the formation of many tornadoes is the development of a mesocyclone. A mesocyclone is a vertical cylinder of rotating air that develops in the updraft of a thunderstorm. The formation of this large vortex begins as strong winds high up in the atmosphere cause winds lower in the atmosphere to roll, as shown in Figure 18A. In Figure 18B, you can see that strong thunderstorm updrafts cause this rolling air to tilt. Once the air is completely vertical (Figure 18C), the mesocyclone is well established. The formation of a mesocyclone does not necessarily mean that a tornado will follow. Few mesocyclones produce tornadoes like the one shown in Figure 19 on page 574.

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Q&A

Q *What is the most destructive tornado on record?*

A The Tri-State Tornado, which occurred on March 18, 1925, started in southeastern Missouri and remained on the ground over a distance of 352 kilometers, until it reached Indiana. Casualties included 695 people dead and 2027 injured. Property losses were also great, with several small towns almost totally destroyed.

Formation of a Mesocyclone

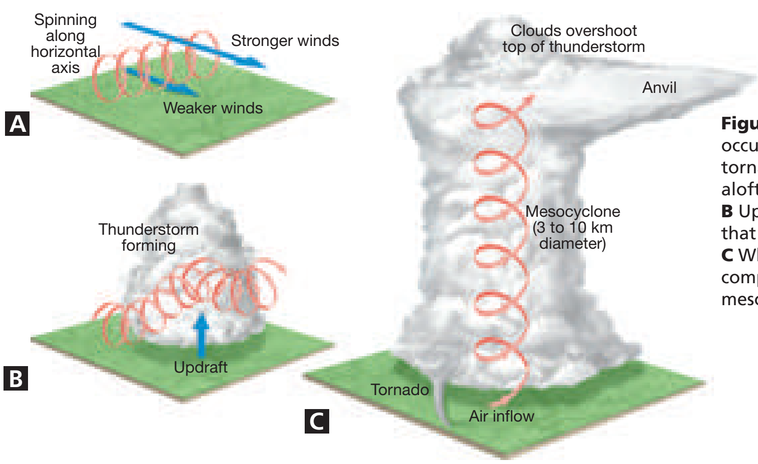


Figure 18 A mesocyclone can occur before the formation of a tornado. **A** First, stronger winds aloft cause lower winds to roll. **B** Updrafts tilt the rolling air so that it becomes nearly vertical. **C** When the rotating air is completely vertical, the mesocyclone is established.

Facts and Figures

The largest recorded tornado was in the high plains of the Texas panhandle near the town of Gruver on June 9, 1971. At times, the tornado was nearly 4 km wide, with an average width of about 2 km. This is probably close to the maximum size for tornadoes, but it is possible that larger, unrecorded tornadoes have occurred.

Tornadoes

Teacher Demo

Homemade Tornado L2

Purpose Students will observe a visual model of a tornado.

Materials piece of sturdy cardboard; glue; 2 transparency sheets; small hand-held, battery-operated fan; small plastic bowl; clear plastic plant dish, approximately 7" in diameter with a hole cut in the middle; water; dry ice

Procedure Glue the plastic bowl to the center of the cardboard. Glue half of one of the transparency sheets to one side of the bowl. Glue the rest of the sheet in a half circle around the bowl without touching the bowl. Glue the second sheet to the opposite side of the cup in the same manner. The two sheets must overlap but not touch. Pour about half a cup of water in the cup. Using gloves, add a few small pieces of dry ice to the water. Place the plant dish upside down on top of the transparencies. Turn on the fan and place it in the hole, facing up to draw air up.

Expected Outcome Students should see the "smoke" from the dry ice form in a tornado pattern as it flows past the transparency sheets with the air being drawn up.
Kinesthetic, Visual

Go Online SciLinks NSTA

Download a worksheet on fronts and severe weather for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 17 *The clouds vary in height, the smallest being the cloud that initiates the storm.*

Reading Checkpoint *During the cumulus stage, strong updrafts supply moist air that causes the cloud to grow vertically. Usually within about an hour of the initial updraft, heavy precipitation is released from the cloud. Gusty winds, lightning, and sometimes hail also are experienced during this stage. Eventually, downdrafts dominate throughout the cloud and the storm dies down.*

Integrate Social Studies

L2

Storm Warnings Accurate storm predictions and warnings can help to minimize the loss of property and of life. The National Weather Service has created a system to inform the public of the likelihood of a storm event in their area. They use the terms *watch* and *warning* to relay the imminent danger. A hurricane watch means that hurricanes are possible in the area within 36 hours. A hurricane warning means that hurricanes are expected in the area within 24 hours. Also a tornado watch means that conditions are favorable for a tornado in the area. A tornado warning means that a tornado has been sighted or has been seen on radar. Challenge students to devise a plan of action that should be taken during a hurricane watch and warning or a tornado watch and warning. Ask them to present their findings to the class in the form of a poster or an emergency bulletin.
Interpersonal

Figure 19 The tornado shown here descended from the lower portion of a mesocyclone in the Texas Panhandle in May, 1996.

Tornado Intensity Pressures within some tornadoes have been estimated to be as much as 10 percent lower than pressures immediately outside the storm. The low pressure within a tornado causes air near the ground to rush into a tornado from all directions. As the air streams inward, it spirals upward around the core. Eventually, the air merges with the airflow of the cumulonimbus cloud that formed the storm. Because of the tremendous amount of pressure change associated with a strong tornado, maximum winds can sometimes approach 480 kilometers per hour. One scale used to estimate tornado intensity is the Fujita tornado intensity scale, shown in Table 1. Because tornado winds cannot be measured directly, a rating on this scale is determined by assessing the worst damage produced by a storm.

Tornado Safety The Storm Prediction Center (SPC) located in Norman, Oklahoma, monitors different kinds of severe weather. The SPC's mission is to provide timely and accurate forecasts and watches for severe thunderstorms and tornadoes. Tornado watches alert people to the possibility of tornadoes in a specified area for a particular time period. A tornado warning is issued when a tornado has actually been sighted in an area or is indicated by weather radar.

Table 1 Fujita Tornado Intensity Scale

Intensity	Wind Speed Estimates (kph)	Typical Damage
F0	< 116	Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	116–180	Moderate damage. Peels surface off roofs; mobile homes pushed off foundations or overturned; moving cars blown off roads.
F2	181–253	Considerable damage. Roofs torn off frame houses; mobile homes demolished; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
F3	254–332	Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	333–419	Devastating damage. Well-constructed houses leveled; structures with weak foundations blown some distance; cars thrown; large missiles generated.
F5	> 419	Incredible damage. Strong frame houses lifted off foundations and carried away; automobile-sized missiles fly through the air in excess of 100 m; bark torn off trees.

Facts and Figures

The deadliest tornado in the United States occurred on March 18, 1925. The so-called Tri-State Tornado killed 695 people as it raced along at 96–117 km/h in a 352 km-long track across parts of Missouri, Illinois, and Indiana, producing F5 damage. This event also holds the known record for most tornado fatalities in a single city or town: at least 234 at Murphysboro, IL.

Hurricanes

If you've ever been to the tropics or seen photographs of these regions, you know that warm breezes, steady temperatures, and heavy but brief tropical showers are the norm. It is ironic that these tranquil regions sometimes produce the most violent storms on Earth. **Whirling tropical cyclones that produce winds of at least 119 kilometers per hour are known in the United States as hurricanes.** In other parts of the world, these severe tropical storms are called typhoons, cyclones, and tropical cyclones.

Regardless of the name used to describe them, hurricanes are the most powerful storms on Earth. At sea, they can generate 15-meter waves capable of destruction hundreds of kilometers away. Should a hurricane hit land, strong winds and extensive flooding can cause billions of dollars in damage and great loss of life. Hurricane Floyd, which is shown in a satellite image in Figure 20, was one such storm. In September 1999, Floyd brought flooding rains, high winds, and rough seas to a large portion of the Atlantic coast. More than 2.5 million people evacuated their homes. Torrential rains caused devastating inland flooding. Floyd was the deadliest hurricane to strike the U.S. mainland since Hurricane Agnes in 1972. Most of the deaths caused by Hurricane Floyd were the result of drowning from floods.

Hurricanes are becoming a growing threat because more and more people are living and working near coasts. At the close of the twentieth century, more than 50 percent of the U.S. population lived within 75 kilometers of a coast. This number is expected to increase even more in the early decades of this century. High population density near shorelines means that hurricanes and other large storms place millions of people at risk.

Q & A

Q *Why are hurricanes given names, and who picks the names?*

A Actually, the names are given once the storms reach tropical-storm status (winds between 61–119 kilometers per hour). Tropical storms are named to provide ease of communication between forecasters and the general public regarding forecasts, watches, and warnings. Tropical storms and hurricanes can last a week or longer, and two or more storms can be occurring in the same region at the same time. Thus, names can reduce the confusion about what storm is being described.

The World Meteorological Organization creates the lists of names. The names for Atlantic storms are used again at the end of a six-year cycle unless a hurricane was particularly destructive or otherwise noteworthy. Such names are retired to prevent confusion when the storms are discussed in future years.

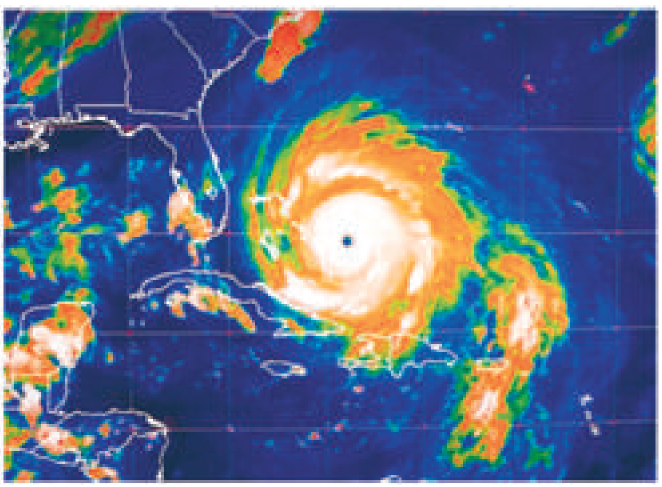


Figure 20 This satellite image of Hurricane Floyd shows its position off the coast of Florida a few days before the hurricane moved onto land. Floyd eventually made landfall near Cape Fear, North Carolina.

Hurricanes

Use Visuals L1

Figure 20 Direct students' attention to the satellite image in the figure. Ask: **What is the direction of air flow in Hurricane Floyd?** *(counterclockwise)* **Visual**

Use Community Resources L2

Invite students to gather first-hand reports of any significant tornadoes or hurricanes in their area. Help them identify good people to interview, and prepare questions in advance. For example: Have there been any especially severe storms in this area? When did this event occur? What damage did it do? Then have students look for quantitative records of the event's intensity, in terms of the Fujita Scale for tornadoes and the Saffir-Simpson Scale for hurricanes. **Interpersonal**

Facts and Figures

Of all the hurricane-prone areas of the United States, Tampa Bay, FL, is considered one of the most vulnerable to severe flooding, damage, and loss of life in a major hurricane. There are several reasons for this. Tampa Bay is located on a peninsula with long stretches of waterfront. This makes the area one of the most densely populated in Florida, and leads to limited evacuation routes. There is also a large population of elderly people in the area. The evacuation of this segment of the population could prove to be difficult for emergency workers. Tampa Bay's geography could also increase the effects of a storm surge; the Gulf of Mexico has a broad, shallow continental shelf on which a storm surge could build to heights great enough to destroy or damage thousands of homes and businesses. The Tampa Bay area has not received a direct hit from a major hurricane in several decades.

Build Science Skills L2

Comparing and Contrasting Ask students to explore the similarities and differences of tornadoes and hurricanes by making a chart. They should include in their chart information on location, associated storms, pressures associated with the storm, impact on society, and maximum wind strength.
Logical

Build Reading Literacy L1

Refer to **p. 502D** in **Chapter 18,** which provides the guidelines for visualizing.

Visualize Ask students to read the section under Development of Hurricanes on p. 576. After the first reading, instruct students to close their eyes and think of a hurricane. Have them suppose they are flying through the clouds of a hurricane and note the changes in wind velocity and pressure as they travel from one side to the other. Have students refer to Figure 21 to help them visualize their trip.
Intrapersonal

Occurrence of Hurricanes Most hurricanes form between about 5 and 20 degrees north and south latitude. The North Pacific has the greatest number of storms, averaging 20 per year. The coastal regions of the southern and eastern United States experience fewer than five hurricanes, on average, per year. Although many tropical disturbances develop each year, only a few reach hurricane status. A storm is a hurricane if the spiraling air has winds blowing at speeds of at least 119 kilometers per hour.

Development of Hurricanes A hurricane is a heat engine that is fueled by the energy given off when huge quantities of water vapor condense. **Hurricanes develop most often in the late summer when water temperatures are warm enough to provide the necessary heat and moisture to the air.** A hurricane begins as a tropical disturbance that consists of disorganized clouds and thunderstorms. Low pressures and little or no rotation are characteristic of these storms.

Occasionally, tropical disturbances become hurricanes. Figure 21 shows a cross section of a well-developed hurricane. An inward rush of warm, moist surface air moves toward the core of the storm. The air then turns upward and rises in a ring of cumulonimbus clouds. This doughnut-shaped wall that surrounds the center of the storm is the **eye wall.** Here the greatest wind speeds and heaviest rainfall occur. Surrounding the eye wall are curved bands of clouds that trail away from the center of the storm. Notice that near the top of the hurricane, the rising air is carried away from the storm center. This outflow provides room for more inward flow at the surface.

At the very center of the storm is the **eye** of the hurricane. This well-known feature is a zone where precipitation ceases and winds subside. The air within the eye gradually descends and heats by compression, making it the warmest part of the storm.

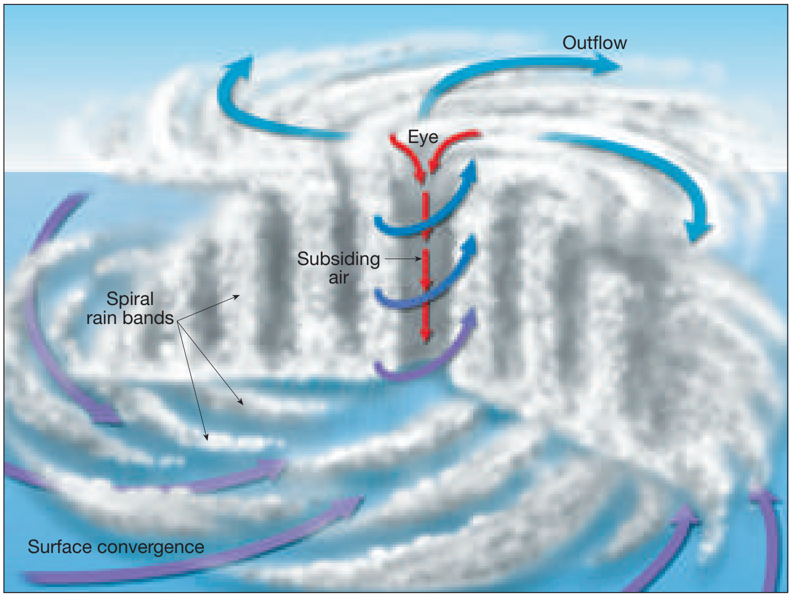


Figure 21 Cross Section of a Hurricane The eye of the hurricane is a zone of relative calm, unlike the eye wall region where winds and rain are most intense.
Describing *Describe the airflow in different parts of a hurricane.*

Facts and Figures

Hurricanes in the past were identified using awkward latitude/longitude methods. It became clear that the use of short, distinctive names would be quicker and less subject to error. These advantages are especially important in exchanging detailed storm information between hundreds of widely scattered stations, coastal bases, and ships at sea. Since 1953, Atlantic tropical storms have been named from lists originated by the National Hurricane Center. The lists featured only women's names until 1979, when men's and women's names were alternated. If a storm is deadly or very costly, the name is never used again.

Hurricane Intensity The intensity of a hurricane is described using the Saffir-Simpson scale shown in Table 2. The most devastating damage from a hurricane is caused by storm surges. A **storm surge** is a dome of water about 65 to 80 kilometers wide that sweeps across the coast where a hurricane's eye moves onto land.

A hurricane weakens when it moves over cool ocean waters that cannot supply adequate heat and moisture. Intensity also drops when storms move over land because there is not sufficient moisture. In addition, friction with the rough land surface causes winds to subside. Finally, if a hurricane reaches a location where the airflow aloft is unfavorable, it will die out.

Table 2 Saffir-Simpson Hurricane Scale

Category	Sustained Wind Speeds (kph)	Typical Damage
1	119–153	Storm surge 1.2–1.5 meters; some damage to unanchored mobile homes, shrubbery, and trees; some coastal flooding; minor pier damage.
2	154–177	Storm surge 1.6–2.4 meters; some damage to buildings' roofs, doors, and windows; considerable damage to mobile homes and piers; moderate coastal flooding.
3	178–209	Storm surge 2.5–3.6 meters; some structural damage to small buildings; some large trees blown over; mobile homes destroyed; some coastal and inland flooding.
4	210–249	Storm surge 3.7–5.4 meters; severe damage to trees and signs; complete destruction of mobile homes; extensive damage to doors and windows; severe flooding inland.
5	> 249	Storm surge >5.4 meters; complete roof failure on many buildings; some complete building failure; all treees and signs blown away; major inland flooding.

Section 20.3 Assessment

Reviewing Concepts

1. What is a thunderstorm?
2. What causes a thunderstorm?
3. What is a tornado?
4. How does a tornado form?
5. What is a hurricane?
6. How does a hurricane form?

Critical Thinking

7. **Formulating Hypotheses** What kind of front is associated with the formation of tornadoes? Explain.
8. **Synthesizing** Explain why a hurricane quickly loses its strength as the storm moves onto land.

Writing in Science

Explanatory Paragraph Examine Tables 1 and 2 to contrast the damage caused by tornadoes and hurricanes. Use the data to explain why even though hurricanes have lower wind speeds, they often cause more damage than tornadoes do.

3 ASSESS

Evaluate Understanding

L2

Have students make a game of concentration using the terms in the chapter and their definitions. Have groups of students write each term on separate index cards and the definition of each term on a second set of index cards. To play the game, students should shuffle all the cards together and then lay them face down in a grid. Each student takes turns flipping over two index cards. If the cards match (definition matches the term), the student can remove the cards from the grid. If the cards do not match, the student places the cards face down. After all of the cards are gone, the student who has removed the most cards wins the match.

Reteach

L1

Use Figures 17, 18, and 21 as visual aids to summarize the development of severe storms.

Writing in Science

Hurricanes generally inflict more damage because they are larger and last longer than tornadoes do.

Section 20.3 Assessment

1. A thunderstorm is a severe storm that generates lightning, thunder, gusty winds, heavy rain, and hail.
2. A thunderstorm forms when relatively warm, humid air rises in an unstable environment.
3. A tornado is a violent rotating column of air that extends downward from cumulonimbus clouds.
4. Most tornadoes form in association with severe thunderstorms.
5. A hurricane is a whirling tropical cyclone that produces wind that can reach 300 km/h.
6. A hurricane develops when water temperatures are warm enough to provide the necessary heat and moisture to the air.
7. Tornadoes often form in thunderstorms that develop along cold fronts because air masses on either side of the front have very different temperature and moisture conditions.
8. There is not sufficient moisture. The rough land surface causes winds to subside.

Answer to . . .

Figure 21 *Air entering the storm from the surface is moving counterclockwise. Air within the eye region is also moving counterclockwise. Outflow, however, is moving in a clockwise direction.*

How the Earth Works

1 FOCUS

Objectives

In this feature, students will
- explain what causes wind and what factors affect wind speed.
- describe the development of the different types of storms.
- summarize the impact of storms.

Reading Focus

Build Vocabulary L2

Key Terms Write these key terms on the board: *wind*, *tornado*, *blizzard*, *tropical cyclone*, *typhoon*, *storm surge*. Ask students to define them. Then have students explain what causes wind and what factors affect wind speed.

2 INSTRUCT

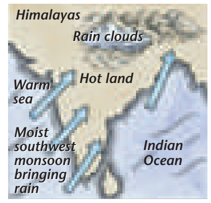
Bellringer L2

Have students read the feature caption heads that name different types of storms. Ask: **Do any of these kinds of storms occur in your region?** If so, have students estimate how frequently the storms occur. Discuss how location and regional climate account for the frequency of storms.
Verbal, Logical

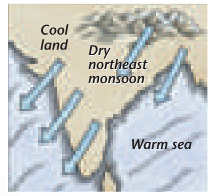
How the Earth Works

Winds and Storms

The world's atmosphere is forever on the move. **Wind,** or air in motion, occurs because solar radiation heats up some parts of the sea and land more than others. Air above these hot spots becomes warmer and lighter than the surrounding air and therefore rises. Elsewhere, cool air sinks because it is heavier. Winds blow because air squeezed out by sinking, cold air is sucked in under rising, warm air. Wind may move slowly as in a gentle breeze. In extreme weather, wind moves rapidly, creating terrifyingly destructive storms.



Southwest Monsoon *During the early summer, the hot, dry lands of Asia draw in cooler, moist air from the Indian Ocean.*



Northeast Monsoon *The cold, dry winter air from Central Asia brings chilly, dusty conditions to South Asia.*

MONSOONS
Seasonal winds called monsoons affect large areas of the tropics and subtropics. They occur in South Asia, southern North America, eastern Australia, and other regions of the world. In South Asia, southwest monsoons generally bring desperately needed rain from May until October.

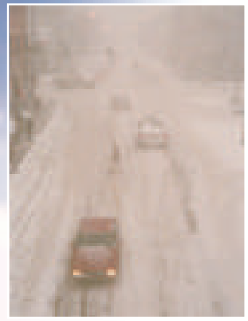
THUNDERSTORMS
Thunderclouds are formed by powerful updrafts of air that occur along cold fronts or over ground heated very strongly by the sun. Ice crystals and water droplets high in the cloud are torn apart and smashed together with such ferocity that they become charged with electricity. Thunderstorms can unleash thunder, lightning, wind, rain, and hail.

LIGHTNING AND THUNDER
Electricity is discharged from a thundercloud in the form of lightning. A bolt of lightning can heat the air around it to a temperature four times as hot as the sun. The heated air expands violently and sends out a rumbling shock wave that we hear as thunder.

Customize for Inclusion Students

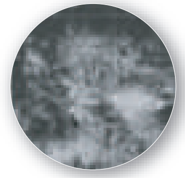
Gifted Explain to students that the term *tropical cyclones* is used to refer to certain hurricanes and typhoons. Have students find out how many tropical cyclones occurred last year and make a chart with the name, dates, and location (ocean) of each storm. Post the chart in your classroom and discuss whether or not there is a pattern in the chart.

TORNADOES
Tornadoes may strike wherever thunderstorms occur. A **tornado** begins when a column of strongly rising warm air is set spinning by high winds at a cloud's top. A funnel is formed and may touch the ground. With winds that can rise above 419 kph, tornadoes can lift people, cars, and buildings high into the air and then smash them back to the ground.

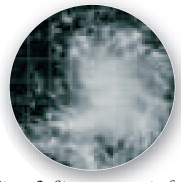


BLIZZARDS
In a **blizzard**, heavy snowfall and strong winds often make it impossible to see. Winds pile up huge drifts of snow. Travel and communication can grind to a halt.

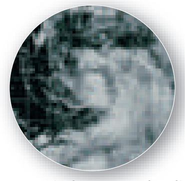
HOW TROPICAL STORMS DEVELOP
Tropical storms begin when water evaporates over an ocean in a hot tropical region to produce huge clouds and thunderstorms. When the storms cluster together and whirl around a low-pressure center, they form a **tropical cyclone.** Tropical cyclones with winds of at least 119 kph are called hurricanes in some regions and **typhoons** in other regions. The sequence below shows satellite images of an Atlantic hurricane.



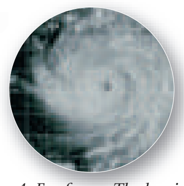
Stage 1: Thunderstorms develop over the ocean.



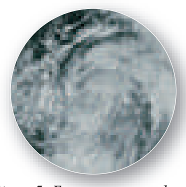
Stage 2: Storms group to form a swirl of cloud.



Stage 3: Winds grow and a distinct center forms in the cloud swirl.



Stage 4: Eye forms. The hurricane is now at its most dangerous.



Stage 5: Eye passes over land. The hurricane starts to weaken.

IMPACT OF TROPICAL STORMS
Tropical storms are often devastating. The strongest winds, with gusts sometimes more than 249 kph, occur at the storm's center, or eye. When a tropical storm strikes land, raging winds can uproot trees and destroy buildings. Vast areas may be swamped by torrential rain, and coastal regions may be overwhelmed by a **storm surge,** a wall of water some 8 m high sucked up by the storm's eye.

These women wade through the streets of Dhaka, Bangladesh, flooded by a tropical cyclone. In 1991, a cyclone killed more than 130,000 Bangladeshis.

A Pacific typhoon struck this ship off the coast of Taiwan in November 2000. Many of the crew members fell victim to the raging sea.

ASSESSMENT

1. **Key Terms** Define **(a)** wind, **(b)** tornado, **(c)** blizzard, **(d)** tropical cyclone, **(e)** typhoon, **(f)** storm surge.
2. **Physical Processes** How do thunderstorms come into being?
3. **Economic Activities** **(a)** How can storms have a negative impact on economic activities? **(b)** How can monsoons benefit economic activities?
4. **Natural Hazards** How can a tropical cyclone result in the loss of thousands of lives?
5. **Critical Thinking** **Developing a Hypothesis** Since 1991, the Bangladeshi government has constructed hundreds of concrete storm shelters in coastal regions of the country. **(a)** Why do you think the government decided on this policy? **(b)** How do you think the policy has benefited the country?

Integrate Social Studies L2

Ask students to discuss which kind of storm seems most threatening to their community and why. Then discuss the kinds of emergency services that are in place to help in case of a storm.
Logical

3 ASSESS

Evaluate Understanding L2

Have students compare and contrast the development of the different types of storms described in the feature (monsoons, thunderstorms, tornadoes, blizzards, and tropical cyclones). Then have students draw diagrams on the board that show how these storms form.

Reteach L1

Have students create flash cards for the key terms *wind*, *tornado*, *blizzard*, *tropical cyclone*, *typhoon*, and *storm surge*. Encourage them to use their flash cards to review the definitions of different types of storms.

Assessment

1. (a) air in motion; **(b)** a spinning column of air with high winds; **(c)** a storm with heavy snowfall and strong winds; **(d)** a cluster of tropical thunderstorms that whirl around a low-pressure center; **(e)** a tropical cyclone that has winds moving at least 74 mph **(f)** a wall of water sucked up by a storm's eye
2. Thunderstorms are formed by powerful updrafts of air that occur along cold fronts or over heated ground. Ice crystals and water droplets high in the cloud are torn apart and smashed together so energetically that they become charged with electricity.
3. (a) During a severe storm, economic activities may come to a halt. When property is destroyed, people spend money to replace or rebuild it. **(b)** Monsoons bring rain to South Asia, and rain is needed to grow crops.
4. Extremely strong winds can destroy buildings, bring torrential rain that results in floods, or cause a storm surge. Any of these can result in loss of life.
5. (a) Bangladesh is located in a region that is subject to tropical storms. The government hopes to offer shelter to the people who are most likely to be affected by the storms. **(b)** Sample answer: It has provided shelter for people who live in coastal areas.

Section 21.1

1 FOCUS

Section Objectives

21.1 **Describe** how latitude affects climate.
21.2 **Describe** how elevation and mountain ranges affect climate.
21.3 **Describe** how large bodies of water affect climate.
21.4 **Describe** how global winds affect climate.
21.5 **Describe** how vegetation affects climate.

Reading Focus

Build Vocabulary L2

LINCS Have students use the LINCS strategy to learn and review the terms *tropical*, *temperate*, and *polar*. In LINCS exercises, students **L**ist what they know about each term, **I**magine a picture that describes the word, **N**ote a "sound-alike" word, **C**onnect the terms to the sound-alike word by making up a short story, and then perform a brief **S**elf test.

Reading Strategy L2

a. Climates get cooler as latitude increases.
b. Climates get cooler as elevation increases.
c. Windward sides of mountains are wet; leeward sides are dry.
d. Places downwind of large water bodies have cooler summers and milder winters.
e. Global winds influence climate by distributing heat and moisture.
f. Vegetation can moderate temperature and increase precipitation.

2 INSTRUCT

Factors That Affect Climate

Build Reading Literacy L2

Refer to **p. 420D** in **Chapter 15**, which provides the guidelines for predicting.

Predict Before students read Factors That Affect Climate, ask: **Why do you think some areas of the world are very hot, and others are very cold?** Once students have a list of predictions, have them read pp. 589–590 and evaluate whether their predictions were correct.
Logical, Interpersonal

21.1 Factors That Affect Climate

Reading Focus

Key Concepts

- How does latitude affect climate?
- How does elevation affect climate?
- What effect does a mountain range have on climate?
- How do large bodies of water affect climate?
- What effect do global winds have on climate?
- How does vegetation affect climate?

Vocabulary

- tropical zone
- temperate zone
- polar zone

Reading Strategy

Summarizing Information Copy the table. As you read, summarize the effect(s) each factor has on climate.

Factor	Effect(s) on Climate
1. Latitude	a. ___?___
2. Elevation	b. ___?___
3. Topography	c. ___?___
4. Water bodies	d. ___?___
5. Global wind	e. ___?___
6. Vegetation	f. ___?___

Figure 1 Maroon Bells Area, Colorado All of Earth's spheres interact to affect climate.
Identifying ***In the photograph, identify at least two components of each of the spheres shown.***

Recall from Chapter 17 that climate includes not only the average weather conditions of an area, but also any variations from those norms. In this section, you will learn that climate involves more than just the atmosphere. Powered by the sun, the climate system is a complex exchange of energy and moisture among Earth's different spheres, all of which are shown in Figure 1.

Factors That Affect Climate

The varied nature of Earth's surface and the many interactions that occur among Earth's spheres give every location a distinctive climate. You will now find out how latitude, elevation, topography, large bodies of water, global winds, and vegetation affect the two most important elements of climate—temperature and precipitation.

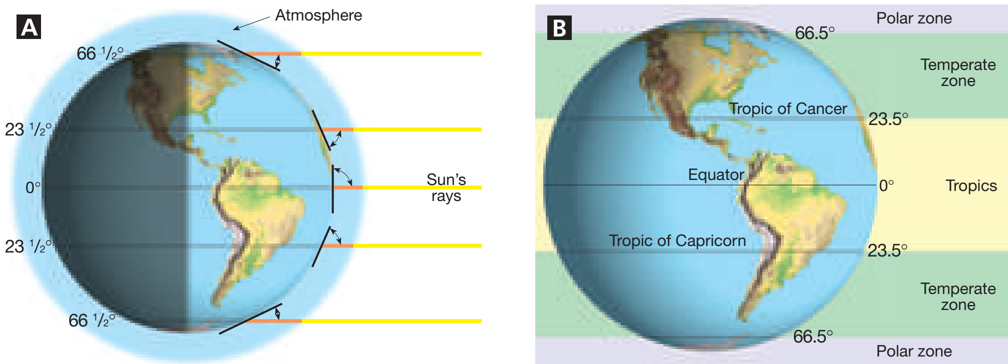


Figure 2 Earth's Major Climate Zones A Solar energy striking Earth's surface near the poles is less intense than radiation striking near the equator.
B Earth can be divided into three zones based on these differences in incoming solar radiation.

Latitude

Latitude is the distance north or south of the equator. **As latitude increases, the intensity of solar energy decreases.** Can you explain why? Study Figures 2A and 2B. Notice that near the equator, the sun's energy strikes the planet at nearly right angles. Therefore, in this region, between about 23.5° north (Tropic of Cancer) and 23.5° south (Tropic of Capricorn) of the equator, the sun's rays are most intense. This region is called the tropics, or the **tropical zones.** Temperatures in the tropical zones are generally warm year-round. In the **temperate zones,** which are between about 23.5° and 66.5° north and south of the equator, the sun's energy strikes Earth at a smaller angle than near the equator. This causes solar energy to be spread out over a larger area. In addition, the length of daylight in the summer is much greater than in the winter. As a result, temperate zones have hot summers and rather cold winters. In the **polar zones,** which are between 66.5° north and south latitudes and the poles, the energy strikes at an even smaller angle, causing the light and heat to spread out over an even larger area. Therefore, the polar regions experience very cold temperatures, even in the summer.

Elevation

Elevation, or height above sea level, is another factor that affects the climate of an area. Recall from Chapter 17 that air temperature decreases with elevation by an average of about 6.5°C Celsius every 1000 meters. **The higher the elevation is, the colder the climate.** The elevation of an area also determines the amount of precipitation it receives. Examine the graph in Figure 3 to see how the climates of two cities at roughly the same latitude are affected by their height above sea level.

Reading Checkpoint *How does the intensity of solar radiation vary at different parts of Earth?*

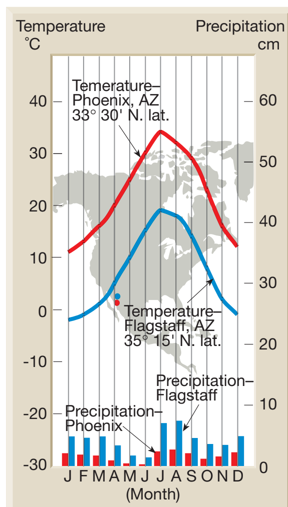


Figure 3 Climate Data for Two Cities This climate graph shows data for two cities in Arizona. Phoenix has an elevation of 338 m. Flagstaff has an elevation of 2134 m.
Interpreting Graphs *How does elevation affect annual temperatures and precipitation?*

Teacher Demo

Heating and Angles

L2

Purpose Students observe how the angle at which light rays strike a surface affects temperature.

Materials black construction paper, metric ruler, scissors, tape, 3 thermometers, 100-W incandescent lamp

Procedure Before the demo, cut three 5 cm × 10 cm rectangles out of black construction paper. Fold them in half and tape them to make pockets. In front of the students, insert the bulb of a thermometer into each pocket. Use books or other props to arrange the thermometers so that one is in a pocket that is flat on the table, one is in a pocket that is at a 45° angle, and the last is in a pocket that is vertical. Make sure the pockets are close together. Have students observe and record the temperature on the thermometers. Place a 100-W incandescent lamp about 30 cm above the pockets and turn it on. Ask students to predict which pocket will heat up fastest. *(Most will say "the flat one.")* Have students observe and record the temperature on the thermometers every 15 minutes. Ask them why they got the results they did. *(The flat pocket heated up the fastest because it was exposed to the most direct rays. The vertical pocket heated up the slowest because it was exposed to the least direct rays.)*

Expected Outcomes The flat pocket will heat up the fastest. The vertical pocket will heat up the slowest.
Logical, Visual

Customize for English Language Learners

Using a cause/effect chart can ensure that students understand the concepts, as well as the word meanings, in this section. Have students work independently or in groups to make a two-column chart. The left column should be labeled "Cause" and the right column "Effect." As students read the section, encourage them to write on their charts different cause/effect relationships about climate. For example, one cause is increasing altitude, and the effect is decreasing temperature.

Answer to . . .

Figure 1 *atmosphere: air and clouds; hydrosphere: lake, ice, and snow; lithosphere: rocks, soil, land, and mountain peaks; biosphere: trees and other vegetation*

Figure 3 *Elevation provides for more precipitation and lower temperatures at least for this comparison.*

Reading Checkpoint *It decreases as latitude increases. Near the equator, the sun strikes the planet most directly. Farther from the equator, the energy spreads out over larger areas.*

Use Visuals L1

Figure 4 Use this diagram to explain how topography affects precipitation. Ask: **What happens to humid air as it is blown up the windward side of the mountains?** *(It cools, forming clouds.)* **What often falls from these clouds?** *(heavy precipitation)* **What is the air like when it reaches the other side of the leeward side of the mountain?** *(very dry)* **What does the term "rain shadow" mean?** *(It refers to an area that rain cannot reach.)*
Visual, Logical

Quick Lab: Observing How Land and Water Absorb and Release Energy L2

Objective
After completing this activity, students will be able to state that land and water absorb and release heat differently.

Skills Focus **Using Models, Comparing and Contrasting, Measuring, Analyzing Data**

Prep Time 10 minutes

Class Time 25–30 minutes

Materials 2 small, identical containers; 2 laboratory thermometers; water; dry sand; masking tape; watch or clock; book; paper towels or rags for spills

Safety Remind students to report any breakage of thermometers immediately. Wipe up any spills at once.

Expected Outcome Students will observe that water warms up and cools down more slowly than land.

Analyze and Conclude
1. The water heated faster than the sand, and the sand cooled more quickly than the water.
2. A large body of water moderates temperatures of an area near that water body, so these areas' temperatures vary less than those over land.
Kinesthetic, Logical

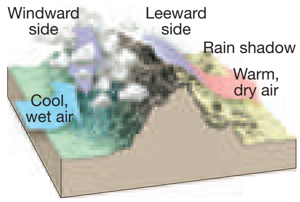


Figure 4 The Rain Shadow Effect Mountains influence the amount of precipitation that falls over an area.
Comparing and Contrasting ***Compare and contrast the climates on either side of a mountain.***

Topography **Topographic features such as mountains play an important role in the amount of precipitation that falls over an area.** As shown in Figure 4, humid air on the windward side of a mountain moves up the mountain's slopes and eventually cools to form clouds. Heavy precipitation often falls from these clouds. By the time air reaches the leeward side of a mountain, much of the moisture is lost. This dry area is called a rain shadow. Rain shadows can extend for hundreds of kilometers downwind of a mountain range.

Water Bodies **Large bodies of water such as lakes and oceans have an important effect on the temperature of an area because the temperature of the water body influences the temperature of the air above it.** Places downwind of a large body of water generally have cooler summers and milder winters than places at the same latitude that are farther inland. In the Quick Lab below, you can observe how a body of water can influence climate.

Quick Lab

Observing How Land and Water Absorb and Release Energy

Materials

2 small, identical containers; 2 laboratory thermometers; water; dry sand; masking tape; watch or clock; book; paper towels or rags for spills

Procedure

1. On a separate sheet of paper, make a copy of the data table shown.
2. Fill one container three-quarters full of dry sand.
3. Fill the other container three-quarters full of water.
4. Place the containers in a sunny area on a flat surface such as a tabletop or a lab bench.
5. Place the bulb of one of the thermometers into the sand. Prop up the thermometer with a book. Tape the thermometer in place so that only the bulb is covered with sand.
6. Repeat Step 5 with the water.
7. Record the initial temperature of each substance in your data table.
8. Record the temperature of each thermometer every 5 minutes for about 20 minutes.
9. Remove the containers from the sunny area.
10. Record the temperature of each thermometer for another 20 minutes.

Analyze and Conclude

1. **Comparing and Contrasting** Which substance heated faster? Which substance cooled faster?
2. **Drawing Conclusions** How does a large body of water affect the temperature of nearby areas?

Heat Absorption and Retention of Water and Sand

	Time	Temp H_2O	Temp Sand		Time	Temp H_2O	Temp Sand
Sunny Area	0			Shady Area	0		
	5				5		
	10				10		
	15				15		
	20				20		

Facts and Figures

Ocean currents also have important effects on climates. Currents moving from low-latitude to high-latitude regions transfer heat from warmer to cooler areas on Earth. For example, the North Atlantic Current is an extension of the Gulf Stream, the warm current that runs up the eastern shore of North America. The North Atlantic Current keeps Great Britain and much of northwestern Europe much warmer during the winter than areas such as Labrador and Alaska that are at similar latitudes.
Cold currents originate in cold high-latitude regions. As they travel towards the equator, they tend to moderate the warm temperatures of adjacent land areas. An example of this is the California Current, which moderates temperatures along the west coast of North America.

Atmospheric Circulation

Global winds are another factor that influences climate because they distribute heat and moisture around Earth. Recall from Chapter 19 that winds constantly move warm air toward the poles and cool air toward the equator. The low-pressure zones at the equator and in the subpolar regions lead to the formation of clouds that drop precipitation as rain or snow.

Figure 5 Arizona Vegetation
A Cacti and scrub are common types of vegetation in the hot, dry climate of Phoenix, Arizona.
B The vegetation in the highlands of Flagstaff, Arizona, is much different.
Formulating Hypotheses ***Which of these areas would receive more precipitation? Why?***

Vegetation

You probably already know that the types of plants that grow in a region depend on climate, as shown in Figures 5A and 5B. But did you know that vegetation affects climate? **Vegetation can affect both temperature and the precipitation patterns in an area.** Vegetation influences how much of the sun's energy is absorbed and how quickly this energy is released. This affects temperature. During a process called transpiration, plants release water vapor from their leaves into the air. So, transpiration influences precipitation. Studies also indicate that some vegetation releases particles that act as cloud seeds. This increase in particles promotes the formation of clouds, which also influences regional precipitation patterns.

Section 21.1 Assessment

Reviewing Concepts

1. How does latitude affect climate?
2. How does elevation affect climate?
3. How does a mountain range affect climate?
4. How do large bodies of water affect climate?
5. What effect do global winds have on climate?
6. Describe different ways in which vegetation affects climate.

Critical Thinking

7. **Comparing and Contrasting** Compare and contrast tropical zones, temperate zones, and polar zones in terms of location and the intensity of solar radiation that each receives.
8. **Explaining** Explain why deserts are common on the leeward sides of mountain ranges.
9. **Applying Concepts** Look again at Figures 3 and 5. What two factors contribute to the average annual temperature in both areas?

Writing in Science

Explanatory Paragraph Write a paragraph to explain how three of the factors discussed in this section affect the climate of your area.

Integrate Biology L2

Biomes Tell students that biologists use the concept of biomes to classify and organize ecosystems. A biome is a particular physical environment that contains a characteristic assemblage of plants and animals. So biomes are defined according to the organisms that live in an area, whereas climates are defined according to temperature and precipitation. Biomes and climates, however, are closely related. Ask: **How do you think temperature affects which types of organisms can live in an area?** *(Some organisms, such as reptiles, cannot survive in cold areas, whereas others are not well adapted to hot areas.)*
Logical

3 ASSESS

Evaluate Understanding L2

Ask students to name a factor that affects climate and describe what effect it has.

Reteach L1

Use Figure 2 to review how solar energy strikes different parts of Earth' surface and how this results in different major climate zones.

Writing in Science

Answers will vary depending on your area.

Answer to . . .

Figure 4 *windward side: wet and cool; leeward side: dry and warm*

Figure 5 *The area around Flagstaff would receive more precipitation because its vegetative cover is greater than that in the area around Phoenix.*

Section 21.1 Assessment

1. As latitude increases, the intensity of the solar energy that strikes an area decreases, and climates become cooler.
2. The higher the elevation, the colder the air and therefore, the colder the climate.
3. windward side: humid air moves up the mountain's slopes and cools to form clouds that produce precipitation; leeward side: the air is warm and very dry
4. Places downwind of a large body of water generally have milder seasons than places farther inland at the same latitude.
5. They move heat and moisture around Earth.
6. It influences how much of the sun's energy is absorbed and released, thereby affecting temperature. Plants release water vapor and influence regional precipitation patterns.
7. All are divisions of Earth based on the intensity of solar energy received. Tropical zones: near equator, the sun's energy strikes Earth at almost 90° angles, causing temperatures to be warm all year round. Temperate zones: north and south of the tropics, the sun's energy strikes Earth at a smaller angle, energy spreads out over a larger area, and yearly temperatures moderate. Polar regions: lie between 66 1/2° north and south latitudes and the poles, solar energy strikes at a more acute angle, spreading it over even a larger area. Polar regions experience very low temperatures year-round due to even smaller angles of sunlight.
8. On the leeward side of a mountain, the air is warm and very dry because moisture condenses on the windward side. This can cause desert conditions for hundreds of kilometers downwind of the mountain.
9. elevation and vegetation

Section 21.2

1 FOCUS

Section Objectives

21.6 **Explain** the Köppen climate classification system.
21.7 **Describe** humid tropical climates.
21.8 **Compare and contrast** humid mid-latitude climates.
21.9 **List** the characteristics of dry climates.
21.10 **List** the characteristics of polar climates.
21.11 **Compare and contrast** highland climates with nearby lowland climates.

Reading Focus

Build Vocabulary L2

Concept Map Have students create concept maps of the Köppen system. Have them start with "Köppen system" at the top, and put the five principal groups of climates on the next level. Below that, they should put the subgroups within each group and, on the last row, details about each climate.

Reading Strategy L2

Students' outlines should be consistent with the information in the chapter and include the temperature and precipitation for each climate type and one location for each climate type.
A2. Tropical Wet and Dry
B1. Humid Mid-Latitude/Mild Winters
B2. Humid Mid-Latitude/Severe Winters
C1. Steppe (semiarid)
C2. Desert (arid)
(Others: Polar Climates, Tundra and Ice Cap; Highland Climates)

2 INSTRUCT

The Köppen Climate Classification System

Build Science Skills L2

Classifying Ask students to classify the five Köppen climate groups into two main groups. Invite several students to give their classifications; then point out that several different answers are possible. Ask students if they think the Köppen system is the only possible way to classify climates. *(no)* Point out that although classification systems are based on facts, they are invented by humans.
Visual, Logical

21.2 World Climates

Reading Focus

Key Concepts

- What is the Köppen climate classification system?
- What are humid tropical climates?
- Contrast the different types of humid mid-latitude climates.
- What are the characteristics of dry climates?
- What are the characteristics of polar climates?
- How do highland climates compare with nearby lowlands?

Vocabulary

- Köppen climate classification system
- wet tropical climate
- tropical wet and dry climate
- humid subtropical climate
- marine west coast climate
- dry-summer subtropical climate
- subarctic climate

Reading Strategy

Outlining Copy and continue the outline for each climate type discussed in this section. Include temperature and precipitation information for each climate type, as well as at least one location with that climate type.

I. World Climates
  A. Humid tropical
    1. Wet tropics
    2. ___?___
  B. Humid mid-latitude
    1. ___?___
    2. ___?___
  C. Dry
    1. ___?___
    2. ___?___

If you were to travel around the world, you would find an incredible variety of climates. So many, in fact, that it might be hard to believe they could all occur on the same planet! Despite the diversity, climates can be classified according to average temperatures and amount of precipitation. In this section, you will learn about the Köppen climate classification system, which is commonly used to group climates.

Figure 6 An ice cap climate is a polar climate in which the average monthly temperature is always below freezing.

The Köppen Climate Classification System

Many classification systems have been used to group climates. Perhaps the best-known and most commonly used system is the Köppen climate classification system. **The Köppen climate classification system uses mean monthly and annual values of temperature and precipitation to classify climates.** This system is often used because it classifies the world into climatic regions in a realistic way.

The Köppen system has five principal groups: humid tropical climates, dry climates, humid mid-latitude climates, polar climates, and highland climates. An example of a polar climate is shown in Figure 6. Note that all of these groups, except climates classified as dry, are defined on the basis of temperature. Dry climates are classified according to the amount of precipitation that falls over an area. Each of the five major groups is further subdivided. See Figure 9 on page 594.

Figure 7 Rain Forest in Malaysia The vegetation in the tropical rain forest is the most luxuriant found anywhere on Earth.

Humid Tropical Climates

Humid tropical climates are climates without winters. Every month in such a climate has a mean temperature above 18°C. The amount of precipitation can exceed 200 cm. There are two types of humid tropical climates: wet tropical climates and tropical wet and dry climates.

Wet Tropical The tropical rain forest shown in Figure 7 is typical of a **wet tropical climate.** Wet tropical climates have high temperatures and much annual precipitation. Why? Recall what you've learned about how latitude affects climate. The intensity of the sun's rays in the tropics is consistently high. Because the sun is directly overhead much of the time, changes in the length of daylight throughout the year are slight. The winds that blow over the tropics cause the warm, humid, unstable air to rise, cool, condense, and fall as precipitation. Look at Figure 9 on pages 594 and 595. Notice that regions with humid tropical climates form a belt on either side of the equator.

Tropical Wet and Dry Refer again to Figure 9. Bordering the wet tropics are climates classified as tropical wet and dry climates. **Tropical wet and dry climates** have temperatures and total precipitation similar to those in the wet tropics, but experience distinct periods of low precipitation. Savannas, which are tropical grasslands with drought-resistant trees, are typical of tropical wet and dry climates. A savanna in Africa is shown in Figure 8.

Figure 8 African Savanna Drought-resistant trees and tall grasses are typical vegetation of a savanna.

Humid Tropical Climates

Build Reading Literacy L1

Refer to **p. 586D,** which provides the guidelines for SQ3R (Study, Question, Read, Recite, Review).

SQ3R Teach this independent study skill as a whole-class exercise. Direct students to skim the section and have them write headings for each section, such as "Humid Tropical Climates." As they skim the section, ask students to write one question for each heading, such as "Why are rain forests so wet?" Then have students write answers to the questions as they read the section. After students finish reading, demonstrate how to recite the questions and answers, explaining that vocalizing concepts in their own words helps them retain what they have learned. Finally, have students review their notes the next day.
Verbal, Interpersonal

Build Science Skills L2

Comparing and Contrasting To help students understand all the information on this page and pp. 596–599, suggest that they focus on a single factor at a time across all the climate regions. For example, first have students compare the climate regions' temperature ranges and sequence them from lowest temperature to highest temperature. Then have students compare the climate regions' precipitation and sequence these amounts from lowest to highest. Discuss any climate region features that are unfamiliar to students. Encourage students who have visited different climate regions to share their experiences.
Logical, Visual

Customize for English Language Learners

As students who are learning English read through the climate region descriptions, encourage them to make a glossary of any unfamiliar terms they encounter. Have them write the English term first, followed by the equivalent word in the student's first language. Encourage students to use the glossary as a reference tool rather than a list to be memorized.

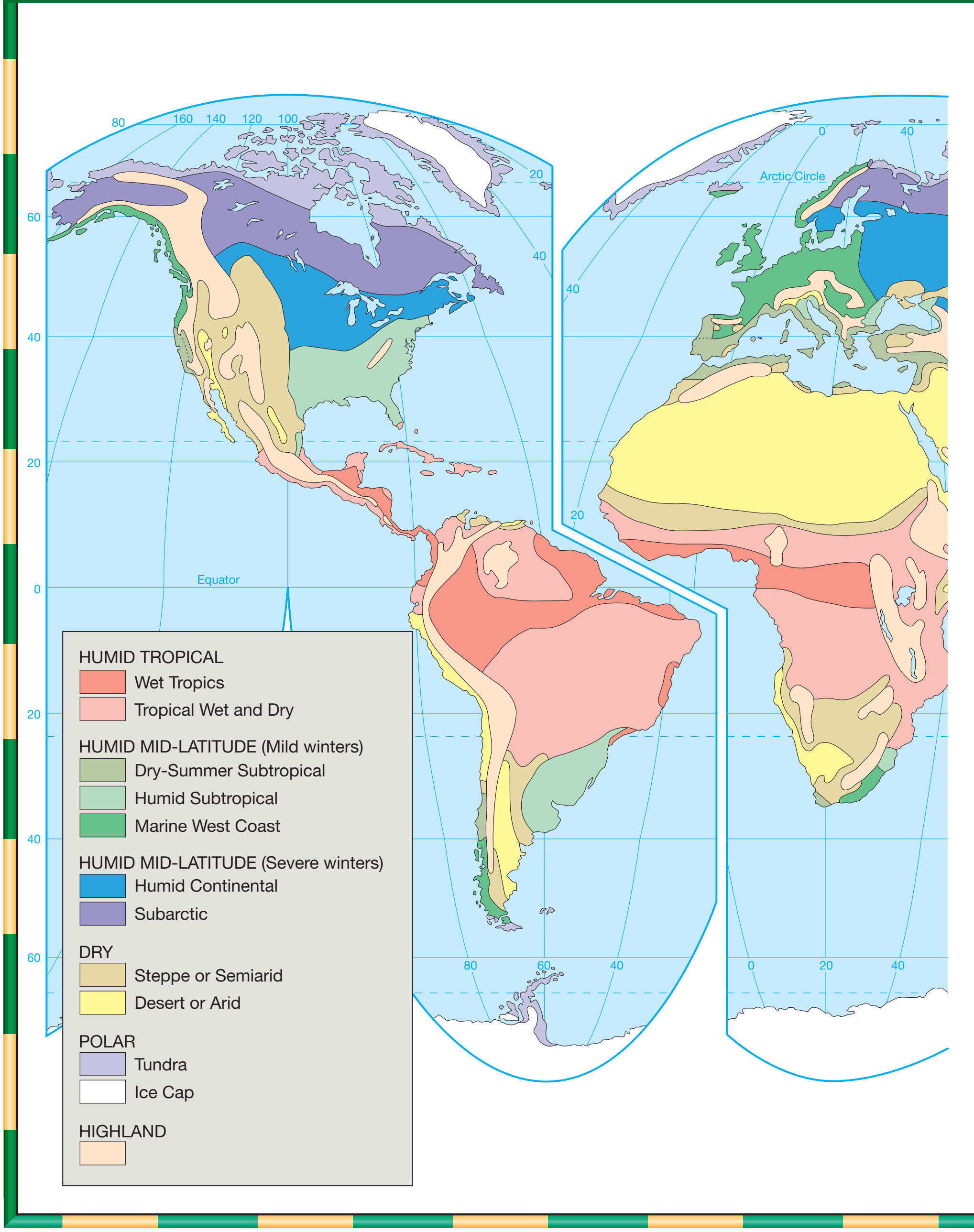
Use Visuals **L1**

Figure 9 Use this map to explain global climates and how they are related. First, orient students to the map by pointing out the equator and lines of latitude. Ask: **How are savannas and rainforests related?** *(Savannas are usually found north and south of rain forests.)* **How are steppes and deserts related?** *(Steppes are usually found north and south of deserts.)* Explain that savannas and steppes are transition zones between rainforests and deserts, respectively, and the next climate zones. **What pattern do you see as you go from south to north in eastern North America?** *(Climates go from subtropical to continental to polar.)*
Visual, Logical

Integrate Biology **L2**

Biomes and Climate Regions
Remind students that biomes are defined according to the organisms that live in an area, whereas climates are defined according to temperature and precipitation. Tell them that Köppen used the distribution of plants to determine climate regions. As a result, many biomes cover the same area as a climate region, and they often have the same names. Ask: **What climate regions seem to be named based on what types of plants are present there?** *(rainforest, desert, tundra, ice cap)* **What is the typical vegetation in a savanna?** *(tropical grasslands with drought-resistant trees)* **What are the typical climate conditions in a rain forest?** *(high temperatures and large amounts of precipitation year-round)*
Logical

Global Climates



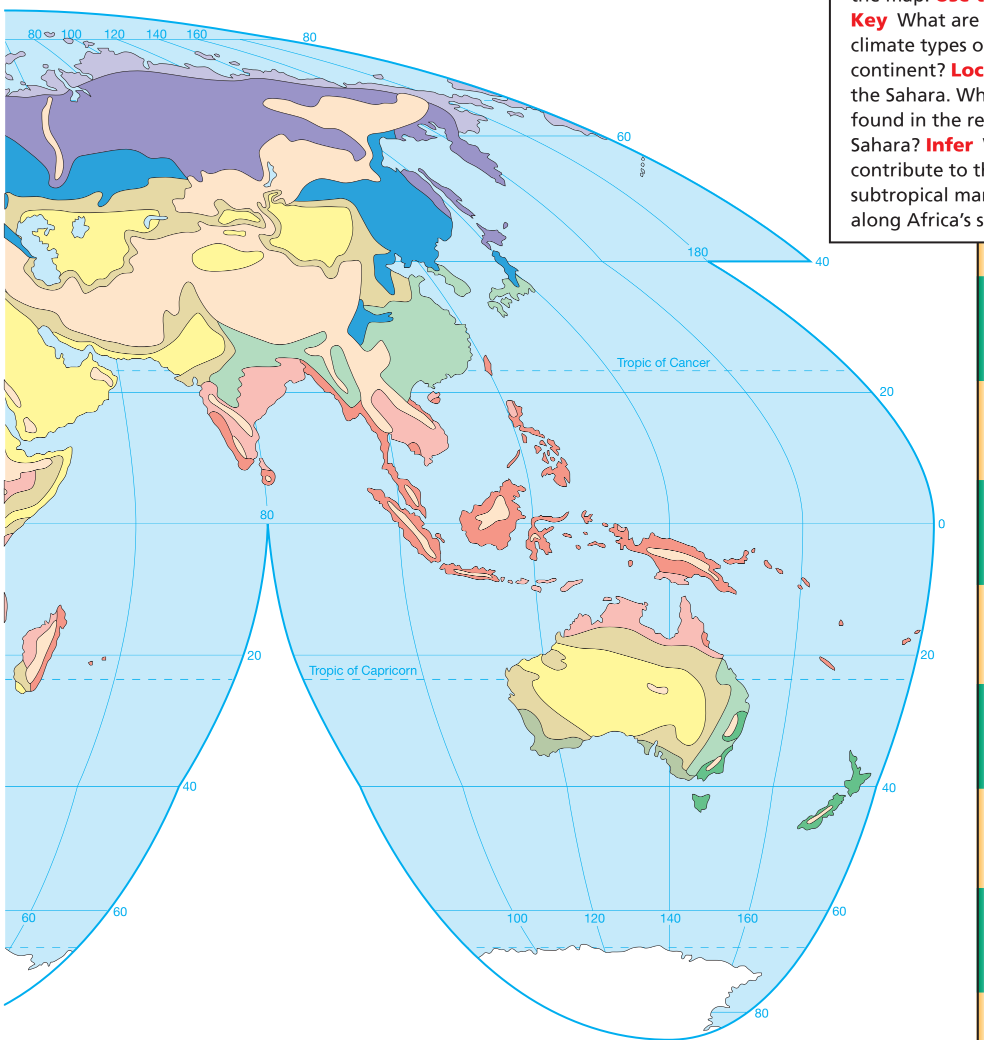
Facts and Figures

Here is an overview of the major groups in the Köppen system:
A. Humid tropical: winterless climates; all months have a mean temperature above 18°C.
B. Dry: climates where evaporation exceeds precipitation; there is a constant water deficiency.
C. Humid mid-latitude: mild winters; average temperature of the coldest month is below 18°C but above −3°C.
D. Humid mid-latitude: severe winters; average temperature of the coldest month is below −3°C; warmest monthly mean exceeds 10°C.
E. Polar: summerless climates; average temperature of the warmest month is below 10°C.

MAP MASTER™ Skills Activity

Figure 9

Regions Find Africa on the map. **Use the Map Key** What are the major climate types of this continent? **Locate** Locate the Sahara. What climate is found in the region of the Sahara? **Infer** What may contribute to the subtropical marine climate along Africa's southern tip?



MAP MASTER™ Skills Activity

Answers

Use the Map Key The major climate types are tropical and dry. A tiny portion of the cape has a subtropical climate. **Locate** The Sahara covers much of the northern part of Africa. The climate in the region of the Sahara is dry desert. **Infer** The subtropical climate at the cape is the result of the onshore flow of warm, ocean air.

Build Science Skills L2

Inferring Invite students to look back at Figure 2 on p. 589 and compare it with Figure 9. Ask: **Since there are only three main zones in Figure 2, why are there so many climate regions in Figure 9?** *(The three zones in Figure 2 are general temperature zones; the climate zones in Figure 9 are based on precipitation as well.)* **Which climate region(s) in Figure 9 span more than one of the zones in Figure 2?** *(dry climates)*
Logical, Visual

Climate 595

Humid Mid-Latitude Climates

Use Visuals

L1

Figure 10 Use this diagram to explain the format of climate graphs. Go over what each axis represents. Make sure students understand that temperature is shown using a line with units on the left axis. Precipitation is shown using bars with units on the right axis. Ask: **In which month does Capetown have the lowest temperature?** *(July)* **The highest temperature?** *(January)* **In which month does Guangzhou have the least precipitation?** *(December)* **The most precipitation?** *(June)*
Visual, Logical

Teacher Demo

Modeling Humid Climates

L2

Purpose Students observe how temperature affects the humidity of a climate.

Materials water, 2 small plastic bowls, transparent plastic wrap, rubber band

Procedure Place equal amounts of water into each of two small plastic bowls. Cover each bowl with transparent plastic wrap and use a rubber band to hold each piece of wrap in place. Place one bowl in a warm location such as a sunny windowsill or near a radiator. Place the other bowl in a cool location. Ask students to predict in which bowl more evaporation will occur. *(Most students will say "the warm one.")* The next day, have students observe the two bowls. Ask them what they observed. *(The warmer bowl had more condensation on the underside of the plastic wrap.)* Ask students how they think this relates to the differences between humid tropical climates and humid mid-latitude climates. *(The higher temperatures in the tropics lead to greater evaporation and greater rainfall than in the mid-latitudes.)*

Expected Outcome The warmer bowl will have more condensation on the underside of the plastic wrap.
Logical, Visual

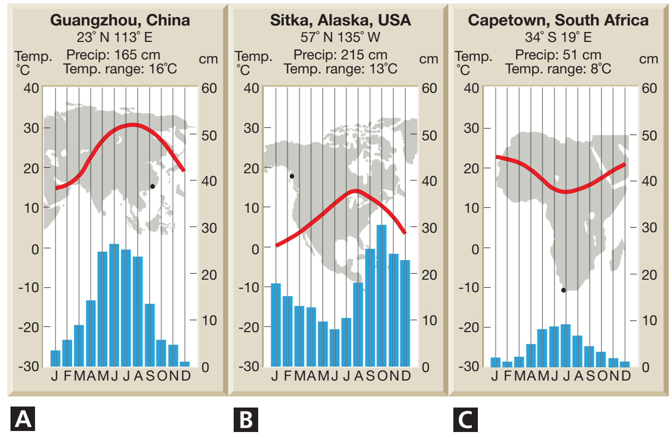


Figure 10 Each of these graphs shows typical climate data of the mid-latitude climates with mild winters. Graph **A** shows a humid subtropical climate. Graph **B** shows a marine west coast climate. Graph **C** shows a dry-summer subtropical climate.

Humid Mid-Latitude Climates

Humid mid-latitude climates include climates with mild winters as well as those with severe winters. **Climates with mild winters have an average temperature in the coldest month that is below 18°C but above −3°C. Climates with severe winters have an average temperature in the coldest month that is below −3°C.**

Humid Mid-Latitude With Mild Winters As you can see in Figure 9, there are three types of humid mid-latitude climates. Located between about 25° and 40° latitude on the eastern sides of the continents are the **humid subtropical climates.** Notice that the subtropical climate dominates the southeastern United States. In the summer, these areas experience hot, sultry weather as daytime temperatures are generally high. Although winters are mild, frosts are common in the higher-latitude areas. The temperature and precipitation data shown in the graph in Figure 10A are typical of a humid subtropical climate.

Coastal areas between about 40° and 65° north and south latitude have **marine west coast climates.** Maritime air masses over these regions result in mild winters and cool summers with an ample amount of rainfall throughout the year. In North America, the marine west coast climate extends as a narrow belt from northernmost California into southern Alaska. The data in Figure 10B are typical of marine west coast climates.

As you can see in Figure 9, regions with **dry-summer subtropical climates** are located between about 30° and 45° latitude. These climatic regions are unique because they are the only humid climate that has a strong winter rainfall maximum, as shown in Figure 10C. In the United States, dry-summer subtropical climate is found only in California. It is sometimes referred to as a mediterranean climate.

Reading Checkpoint *Describe the conditions typical of a humid subtropical climate.*

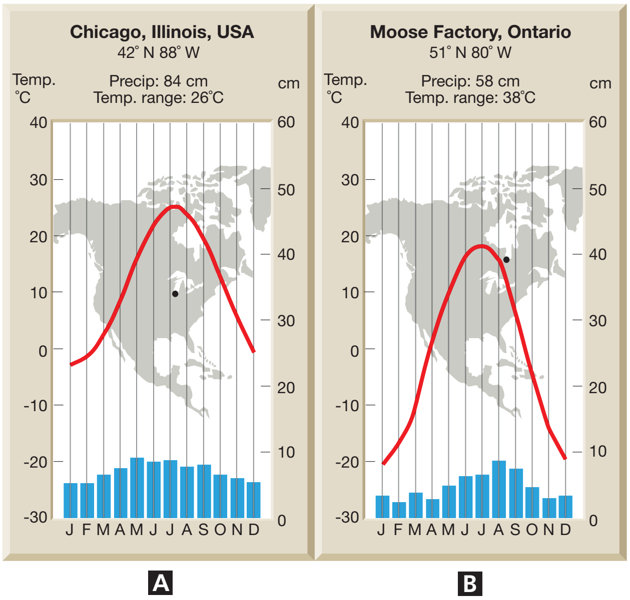


Figure 11 Graph **A** displays data typical of a humid continental climate. The trends shown in graph **B** are typical of a subarctic climate.
Interpreting Graphs *What are the typical temperatures and amounts of precipitation for Chicago, Illinois, in May and June?*

Humid Mid-Latitude With Severe Winters There are two types of humid mid-latitude climates with severe winters: the humid continental climates and the subarctic climates. Continental landmasses strongly influence both of these climates. As a result, such climates are absent in the Southern Hemisphere. There, oceans dominate the middle-latitude zone. Locate the regions having a humid continental climate, which are shown in blue, on Figure 9. Note that areas with such climates lie between approximately 40° and 50° north latitude. As you can see in Figure 11A the winters are severe, while the summers are typically quite warm. Note, too, that precipitation is generally greater in summer than in winter.

North of the humid continental climate and south of the tundra is an extensive **subarctic climate** region. From Figure 9, you can see that this climate zone covers a broad expanse. Such climates stretch from western Alaska to Newfoundland in North America, and from Norway to the Pacific coast of Russia in Eurasia. Winters in these regions are long and bitterly cold. By contrast, summers in the subarctic are remarkably warm but very short. The extremely cold winters and relatively warm summers combine to produce the highest annual temperature ranges on Earth.

Reading Checkpoint *Compare and contrast two types of humid mid-latitude climates with severe winters.*

Facts and Figures

Winters in the subarctic region are nearly as cold as those in polar regions. Winter minimum temperatures are among the lowest ever recorded outside the ice sheets of Greenland and Antarctica. In fact, for many years the world's lowest temperature was attributed to Verkhoyansk in east central Siberia, where the temperature dropped to −68°C on February 5 and 7, 1892. Over a 23-year period, this same station had an average monthly minimum of −62°C during January. Although exceptional, these temperatures illustrate the extreme cold that envelops the subarctic region in winter.

Address Misconceptions L2

Students may think that the term *taiga* refers to the entire coniferous forest of the Northern Hemisphere. Explain that although some books use the term that way, the *taiga* is really only the northern part of the coniferous forest. The word *taiga* is Russian, and it refers to the forests just south of the tundra. The term *boreal forest* is also often used for this region.
Logical, Verbal

Address Misconceptions L2

Students may think that it never gets very hot in subarctic areas such as Alaska. Dispel this misconception by pointing out that summer temperatures in southern Alaska are usually between 15°–25° C). Also tell students that the record high temperature in Alaska is 38°C. This record was set on June 27, 1915, in Fort Yukon, a town along the Arctic Circle in the interior of Alaska.
Logical

Use Community Resources L2

Invite a climatologist from a local college into the classroom to discuss climate regions and the factors that cause each one. Ask students to prepare questions in advance to ask the visitor.
Interpersonal

Answer to . . .

Figure 11 *Temperatures range from about 10°C to 20°C. Precipitation is nearly 10 cm.*

Reading Checkpoint *Hot, sultry summers with high daytime temperatures and afternoon or evening thunderstorms are common. Winters are mild, and the precipitation that falls then is in the form of snow.*

Reading Checkpoint *Both are strongly influenced by continental landmasses. Humid continental climates experience severe temperatures, and precipitation is generally greater in summer than in winter. Subarctic climates have winters that are long and bitterly cold and summers that are remarkably warm but short. These differences combine to produce the highest annual temperature ranges on Earth.*

Dry Climates

MAP MASTER Skills Activity

Answers

Locate 1. Atacama Desert; 2. Sonoran Desert; 3. Simpson Desert; 4. Great Indian Desert; 5. Namib Desert and Kalahari Desert

Describe About 40 percent of Australia is desert.

Address Misconceptions **L2**

Students may think that the terms *arid* and *drought* have roughly the same meaning. Explain that droughts occur temporarily as a result of atmospheric conditions. In contrast, arid regions are those where low rainfall is a permanent feature of the climate.
Logical, Verbal

Extent of Dry Climate Zones

MAP MASTER Skills Activity

Figure 12

Location Locate each of the places listed.
Identify Identify the desert(s) in each place or region.

1. Chile
2. southwestern United States
3. central Australia
4. northwestern India
5. southern Africa

Describe About how much of Australia has a desert climate?

Q&A

Q *Are deserts always hot?*

A Deserts can certainly be hot places. The record high temperature for the United States, 57°C, was set at Death Valley, California. However, deserts also experience very cold temperatures. The average daily minimum in January in Phoenix, Arizona, is 1.7°C, a temperature just barely above freezing. At Ulan Bator in Mongolia's Gobi Desert, the average high temperature in January is only −19°C!

Dry Climates

A dry climate is one in which the yearly precipitation is not as great as the potential loss of water by evaporation. In other words, dryness is not only related to annual rainfall, but is also a function of evaporation. Evaporation, in turn, is closely dependent upon temperature. There are two types of dry climates: arid or desert and semi-arid or steppe, as shown in Figure 12. These two climate types are classified as BW and BS, respectively, in the Köppen classification system. Arid and semi-arid climates have many features in common. In fact, the difference between them is slight. The steppe is a marginal and more humid variant of the desert. The steppe represents a transition zone that surrounds the desert and separates it from humid climates.

Dry climates exist as the result of the global distribution of air pressure and winds. In regions near the tropics of Cancer and Capricorn, air is subsiding. When air sinks, it is compressed and warmed. Such conditions are opposite of those needed for clouds to form precipitation. As a result, regions with dry climates experience mostly clear, sunny skies and dry climates. Other dry areas including the Great Basin in North America and the Gobi Desert of Eurasia occur where prevailing winds meet mountain barriers. These arid regions are called rain shadow deserts.

Polar Climates

Polar climates are those in which the mean temperature of the warmest month is below 10°C. Winters in these regions are periods of perpetual night, or nearly so, making temperatures at most polar locations extremely cold. During the summer months, temperatures remain cool despite the long days. Very little precipitation falls in polar regions. Evaporation, too, in these areas is limited.

There are two types of polar climates. The tundra climate, like that shown in Figure 13, is a treeless region found almost exclusively in the Northern Hemisphere. The ice cap climate does not have a single monthly mean above 0°C. Little vegetation grows and the landscape in these regions is covered by permanent ice and snow. Ice cap climates occur in scattered high mountain areas and in Greenland and Antarctica.

Highland Climates

The climate types discussed so far are very similar from place to place and extend over large areas. Some climates, however, are localized, which means that they are much different from climates in surrounding areas. One such climate is a highland climate. Conditions of highland climates often vary from one place to another. For example, south-facing slopes are warmer than north-facing slopes, and air on the windward sides of mountains is wetter than air on the leeward sides. **In general, highland climates are cooler and wetter than nearby areas at lower elevations.** Locate the highland climate regions on Figure 9. What do they all have in common?

Figure 13 Tundra North of Nome, Alaska Tundra plant life includes mostly mosses, shrubs, and flowering herbs.

Go Online SCiLINKS NSTA

For: Links on climates of the world
Visit: www.SciLinks.org
Web Code: cjn-6212

Section 21.2 Assessment

Reviewing Concepts

1. What is the Köppen climate classification system?
2. Describe the characteristics of humid tropical climates.
3. What are some characteristics of humid mid-latitude climates?
4. What defines a dry climate?
5. What are the characteristics of polar climates?
6. How do highland climates compare with nearby lowlands?

Critical Thinking

7. **Identifying** Use Figure 9 to identify the climate type of your city. Describe some characteristics of your city's climate type.
8. **Formulating Conclusions** Can tundra climates exist at low latitudes? Explain.

Writing in Science

Explanatory Paragraph Write a paragraph in which you explain why Antarctica can be classified as a desert.

Polar Climates

Build Science Skills L2

Inferring Have students refer back to Figure 9 on pp. 594–595. Discuss why polar climates occur where they do. Ask: **Why are tundra climates found almost exclusively in the Northern Hemisphere?** *(There is very little land in the Southern Hemisphere that is at the same latitude as tundra climates in the Northern Hemisphere.)*
Visual, Logical

Highland Climates

Build Science Skills L2

Applying Concepts Have students refer back to Section 21.1 to help them understand what causes highland climates. Ask: **What two main factors cause highland climates?** *(elevation and topography)* **What effect does elevation have on highland climates?** *(Temperature decreases with elevation, so highland climates are cooler than nearby climates at lower elevations.)*
Visual, Logical

3 ASSESS

Evaluate Understanding L2

Describe characteristics of various climate regions, and call on students to identify them. For example, if you say "very cold with no plants," students should respond "ice cap."

Reteach L1

Use Figure 9 to review the characteristics of each climate region and subregion.

Writing in Science

Deserts are dry climates that are defined primarily by the amount of precipitation that falls rather than temperature. Antarctica and other areas in Earth's polar regions are deserts because they receive very little precipitation that does not evaporate much annually.

Section 21.2 Assessment

1. The Köppen system uses mean monthly and annual values of temperature and precipitation to classify climates.
2. Humid tropical climates have no winters. Every month has a mean temperature above 18°C and has a lot of precipitation.
3. Humid mid-latitude climates with mild winters have an average temperature in the coldest month that is below 18°C but above −3°C. Humid mid-latitude climates with severe winters have an average temperature in the coldest month that is below −3°C.
4. both the amount of precipitation that falls and the amount that can be lost as the result of evaporation
5. Polar climates are extremely cold, even in the summer months. Very little precipitation falls in polar regions, and evaporation is limited.
6. Highland climates generally are cooler and wetter than nearby places at lower elevations.
7. Answers will vary depending on your location. If necessary, have students use a map.
8. yes, at high elevations where temperatures are very low

Go Online NSTA SCiLINKS

Download a worksheet on climates of the world for students to complete, and find additional teacher support from NSTA SciLinks.

Section 21.3

1 FOCUS

Section Objectives

21.12 **Describe** natural processes that can cause changes in climate.
21.13 **Explain** the greenhouse effect.
21.14 **Define** global warming.
21.15 **List** some of the consequences of global warming.

Reading Focus

Build Vocabulary L2

Paraphrase Explain the meaning of the vocabulary words by using terms that are familiar to students. For example, tell students that *global* can be though of as "globe-like." Point out a classroom globe as an example.

Reading Strategy L2

a. Volcanic Eruptions
b. Possible increase in the amount of solar radiation reflected back to space can cause lower temperatures.
c. Ocean Circulation
d. Changes can result in short-term climate fluctuations.
e. Earth Motions
f. Geographic changes in Earth's land and water due to Earth motion cause changes in climate.

2 INSTRUCT

Natural Processes That Change Climate

Address Misconceptions L2

Students may think that Earth's climate was exactly the same for millions of years, and only changed recently as a result of human activity. Point out that there have been many major natural changes in Earth's history. For example, during the Ice Ages that began 2 to 3 million years ago Earth's climate was much colder. At other times Earth's climate has been much warmer than it is now. Emphasize that there are many different causes of climate change, and that human action is just one of them.
Logical

21.3 Climate Changes

Reading Focus

Key Concepts

- Describe natural processes that can cause changes in climate.
- What is the greenhouse effect?
- What is global warming?
- What are some of the consequences of global warming?

Vocabulary

- greenhouse effect
- global warming

Reading Strategy

Identifying Cause and Effect Copy the table. Identify the causes and effects of climate change presented in this section.

Climate Changes	
Causes	**Effects**
a. ___?___	b. ___?___
c. ___?___	d. ___?___
e. ___?___	f. ___?___

Like most conditions on Earth, climate is always changing. Some of these changes are short-term. Others occur over long periods of geologic time. Some climate changes are the result of natural processes, such as the volcanic eruption shown in Figure 14. Others are related to human activities. In this section, you will learn about some of the ways in which climate changes.

Natural Processes That Change Climate

Many different natural processes can cause a climate to change. Some of the climate-changing processes that you will learn about include volcanic eruptions as well as changes in ocean circulation, solar activity, and Earth motions.

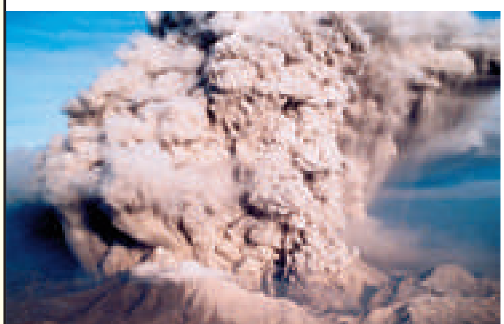


Figure 14 Eruption of Mount Pinatubo

Volcanic Eruptions As you can see in Figure 14, volcanic eruptions can emit large volumes of ash and dust into Earth's atmosphere. What you can't see in the photograph is that volcanic eruptions also send minute particles containing sulfur, into the air. If the volume of these very fine particles called aerosols, is great enough, it can cause short-term changes in Earth's surface temperature. Can you hypothesize why? **The presence of aerosols (volcanic ash, dust, and sulfur-based aerosols) in the air increases the amount of solar radiation that is reflected back into space. This causes Earth's lower atmosphere to cool.**

Ocean Circulation Recall from Chapter 19 that El Niño is a change in ocean circulation that causes parts of the eastern tropical Pacific Ocean to become warmer than usual. **These changes in ocean circulation also can result in short-term climate fluctuations.** For example, some areas that are normally arid receive large amounts of rain during El Niño. Refer to Figure 15. Also, some regions that receive abundant precipitation may experience dry periods when ocean circulation patterns change.

Solar Activity The most studied hypotheses for the causes of climate change are based on changes in the output of solar energy. When the sun is most active, it contains dark blemishes called sunspots. The formation of sunspots appears to correspond with warm periods in Europe and North America. Although variations in solar output may cause short-term climatic change, no evidence for long-term variations due to solar activity exist.

Figure 15 Effect of El Niño In 1998, bad weather conditions and flooding in Alabama were attributed to El Niño.

Earth Motions A number of Earth motions are thought to cause changes in climate. Most of these changes are long-term changes. Tectonic plate movements, for example, cause the crust and upper mantle to move slowly over Earth's surface. These movements cause ocean basins to open and close. Plate movements also cause changes in the positions of landmasses. **These geographic changes in Earth's land and water bodies cause changes in climate.**

Changes in the shape of Earth's orbit and the tilt of Earth on its axis are other Earth motions that affect global climates. Earth's orbit, or path around the sun, is always elliptical. But over a 100,000-year period, the path becomes more and then less elliptical. This change in shape brings Earth closer to and then farther from the sun. This affects global climates. Like its orbit, the tilt of Earth on its axis changes about 2 degrees over a 41,000-year period. Because the angle of tilt varies, the severity of the seasons also changes. The smaller the tilt, the smaller the temperature difference between summer and winter.

Reading Checkpoint *Identify four natural processes that can result in climate changes.*

Build Reading Literacy L1

Refer to **p. 334D** in **Chapter 12,** which provides the guidelines for outlining.

Outline Have students read the text in this section about climate change. Then, have students use the headings as major divisions in an outline. Have students refer to their outlines when answering the questions in the Section 21.3 Assessment.
Verbal, Logical

Teacher Demo

Earth's Motions and Climate L2

Purpose Students observe how changes in Earth's motions affect Earth's climate.

Materials globe, lamp

Procedure If necessary, review what causes the seasons on pp. 481–482 in Chapter 17. Use a globe and a lamp to demonstrate how changes in the shape of Earth's orbit and tilt of Earth's axis can affect global climate. First, set the lamp in the middle of a table and turn it on. Move the globe around the lamp in a circular motion. Then move the globe around the lamp in a more elliptical (oval) motion. Ask students how they think this movement would affect climates. *(It could increase the differences between the seasons.)* Next, increase the tilt of the globe's axis and again move the globe around the lamp. Ask students how they think this would affect climates. *(It would decrease the total amount of sunlight Earth would receive, and therefore lower global temperatures.)*

Expected Outcome Students will understand how changes in Earth's motions affect Earth's climate.
Logical, Visual

Customize for Inclusion Students

Gifted Many scientists think that global warming is not entirely caused by carbon dioxide emissions. They predict that global warming will have positive consequences for some parts of the world. There is also debate over the relative benefits of various attempts to slow global warming. Invite gifted students to research different views of global warming and report back to the class. Some Web sites where they can begin their research include:
http://www.cato.org/current/global-warming/index.html
http://www.marshall.org/subcategory.php?id=9
http://cfa-www.harvard.edu/press/pr0310.html

Answer to . . .

Reading Checkpoint *Volcanic eruptions, changes in global ocean circulation, solar activity, and certain Earth motions can cause changes in climate.*

Human Impact on Climate Changes

Address Misconceptions L2

Students may be misled by the term *greenhouse effect*. The term may make them think that the atmosphere is heated in exactly the same way as a greenhouse. The term was coined to describe the process that heats the atmosphere because it was once thought that greenhouses were heated in a similar way. One factor in heating a greenhouse is the blocking of heat radiation. However, a more important factor is that the glass of the greenhouse prevents warm air from escaping by convection.
Logical

Use Visuals L1

Figure 16 Use these graphs to explain how carbon dioxide emissions affect carbon dioxide concentrations in the atmosphere. Make sure that students understand that the emissions amounts and atmospheric concentrations in graph B are shown in different units. Ask: **What unit is used for carbon dioxide emissions?** *(gigatons of carbon/yr)* **What unit is used for carbon dioxide concentrations in the atmosphere?** *(ppm, or parts per million)* **What does graph C show?** *(carbon dioxide concentrations in the atmosphere)*
Visual, Logical

Address Misconceptions L2

Students often think that the greenhouse effect and global warming are the same phenomenon. Emphasize that the greenhouse effect occurs naturally and is essential to keeping the atmosphere warm enough for living things to survive on Earth. Global warming, on the other hand, is an increase in the temperature of Earth's atmosphere that may be caused or influenced by human activities.
Logical

Human Impact on Climate Changes

Natural processes have certainly contributed to many climatic changes throughout Earth's 4.6-billion year history. These processes will also be responsible for some of the future shifts in Earth's climates. Besides these processes of nature, human activities have contributed and will contribute to global climatic change.

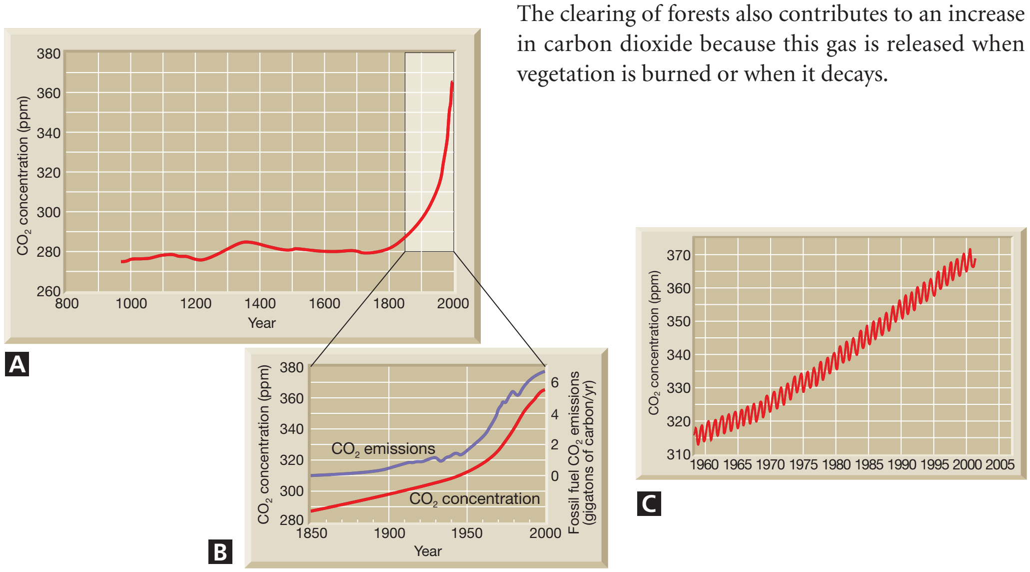
The Greenhouse Effect

The greenhouse effect is a natural warming of both Earth's lower atmosphere and Earth's surface. The major gases involved in the greenhouse effect are water vapor and carbon dioxide. These greenhouse gases, as they are often called, are transparent to incoming solar radiation and therefore much of this energy reaches Earth's surface. Most of this energy is then reradiated skyward. The greenhouse gases are good absorbers of Earth's radiation, which accounts for the warm temperatures of the lower atmosphere.

The greenhouse effect is very important because it makes life as we know it possible on Earth. Without this effect, Earth would be much too cold to support any kind of complex life forms. However, an increase in the greenhouse effect could also prove devastating to Earth's billions of organisms.

Studies indicate that human activities for the past 200 or so years have had a huge impact on the greenhouse effect. As you can see in Figure 16, carbon dioxide levels in the air have risen at a rapid pace since about 1850. Much of this greenhouse gas has been added by the burning of fossil fuels such as coal, petroleum, and natural gas. The clearing of forests also contributes to an increase in carbon dioxide because this gas is released when vegetation is burned or when it decays.

Figure 16 The rapid increase in carbon dioxide concentration since 1850 has closely followed the increase in carbon dioxide emissions from burning fossil fuels. **Inferring** ***What do you think initiated this increase in carbon dioxide levels?***



Facts and Figures

Human influence on regional and global climates likely began long before the beginning of the modern industrial period. There is evidence that humans have been modifying the environment over extensive areas for thousands of years. The use of fire and the overgrazing of marginal lands by domestic animals have reduced the abundance and distribution of plants. Altering ground cover has affected important climate factors such as surface albedo, evaporation rates, and surface winds.

Global Warming As a result of increases in carbon dioxide levels, as well as other greenhouse gases, global temperatures have increased. **This increase is called global warming.** Refer to Figure 17. Note that during the twentieth century, Earth's average surface temperatures increased about 0.6°C. Scientists predict that by the year 2100, temperatures will increase by 1.4°C to 5.8°C. How will these temperature increases affect Earth?

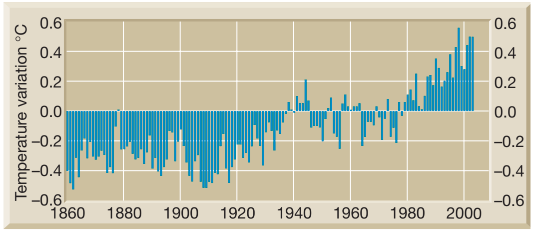


Figure 17 Increases in the levels of greenhouse gases have caused changes in Earth's average surface temperatures.
Interpreting Graphs ***What year was the warmest to date?***

Warmer surface temperatures increase evaporation rates. This, in turn, increases the amount of water vapor in the atmosphere. Water vapor is an even more powerful absorber of radiation emitted by Earth than is carbon dioxide. Therefore, more water vapor in the air will magnify the effect of carbon dioxide and other gases.

Temperature increases will also cause sea ice to melt. Ice reflects more incoming solar radiation than liquid water does. The melting of the ice will cause a substantial increase in the solar energy absorbed at the surface. This, in turn, will magnify the temperature increase created by higher levels of greenhouse gases. The melting of sea ice and ice sheets will also cause a global rise in sea level. This will lead to shoreline erosion and coastal flooding.

Scientists also expect that weather patterns will change as a result of the projected global warming. More intense heat waves and droughts in some regions and fewer such events in other places are also predicted. What other consequences of global warming do you think might occur?

Go Online SCiLINKS NSTA

For: Links on the carbon cycle/global warming
Visit: www.SciLinks.org
Web Code: cjn-6213

Section 21.3 Assessment

Reviewing Concepts

1. Describe four natural processes that can cause climate change.
2. What is the greenhouse effect?
3. What is global warming?
4. What are some of the possible effects of global warming?

Critical Thinking

5. **Formulating Hypotheses** Which would have a longer effect on climate changes—volcanic ash and dust or the same volume of sulfur-based aerosols? Why?
6. **Formulating Conclusions** How do you think cloud cover might change as the result of global warming?
7. **Synthesizing** How might global warming affect Earth's inhabitants, including humans?

Writing in Science

Persuasive Paragraphs Write at least two paragraphs to persuade your friends and family to reduce their consumption of fossil fuels. Be sure to explain why the usage of such energy sources should be reduced.

3 ASSESS

Evaluate Understanding L2

Ask students to describe three natural processes that change climate. Have them describe how each process works.

Reteach L2

Have students write several sentences that briefly explain what the greenhouse effect is.

Writing in Science

Answers will vary but should include an explanation of how burning fossil fuels is thought to be increasing global temperatures and why reducing the usage of fossil fuels will slow this increase.

Go Online NSTA SCiLINKS

Download a worksheet on the carbon cycle/global warming for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 16 *Industrialization has greatly contributed to the rise in carbon dioxide levels in Earth's atmosphere.*

Figure 17 *1998*

Section 21.3 Assessment

1. volcanic eruptions (gases and solids trap and radiate solar energy back to space); ocean circulation patterns cause changes in atmospheric circulation that can result in drought and flooding; changes in solar activity coincide with global changes in temperature; Earth motions, including tectonism and revolution, also cause climates to change.
2. The greenhouse effect is a natural warming of both Earth's lower atmosphere and its surface that is caused by complex reactions between gases and particles in the air.
3. the term for an increase in global temperatures, due to increased levels of greenhouse gases
4. short-term and long-term changes in temperature and precipitation patterns that can result in both wetter-than-normal periods and drier-than-normal periods; a rise in sea level; an increase in shoreline erosion
5. sulfur-based aerosols tend to remain suspended in the air longer than their solid counterparts.
6. Global warming would probably produce an increase in cloud cover due to the higher moisture content of the air. Clouds would also produce opposite effects: they could diminish the amount of solar energy available to heat the atmosphere, and they could absorb and emit radiation that would otherwise be lost from the troposphere.
7. It could harm or kill ocean organisms; cause both land and water habitats to shift or be destroyed; increase the spread of diseases; and increase drought, heat waves, and flooding.

How the Earth Works

1 FOCUS

Objectives

In this feature, students will
- describe where the world's coniferous forests are located.
- recognize the features that enable conifers to withstand long, cold winters.
- identify the behaviors and adaptations that enable animals to survive in northern coniferous forests.

Reading Focus

Build Vocabulary L2

Word Origins Point out to students that *coniferous* sounds very much like another scientific term, *carnivorous*. Have them contrast the origins of these words. *(*Coniferous *comes from Latin and Greek roots that mean "cone-bearing."* Carnivorous *comes from the Latin words* caro*, which means "flesh," and* vorare*, which means "to swallow up.")* Encourage students to use both words correctly in sentences.

2 INSTRUCT

Bellringer L2

Have students list three features that make evergreen trees different from other trees. *(Lists might include pointy leaves or needles, pine cones, and staying green all year.)* Have students list types of trees found in their region. Then ask: **Are the trees you listed conifers or deciduous trees? How do you know? Verbal, Logical**

How the Earth Works

Coniferous Forests

The world's largest forests extend across the far north, where winters can last for eight months. These dense **coniferous forests** consist of spruces, pines, and other trees that carry their seeds in cones. They are particularly suited for coping with cold conditions. Animals in northern forests find plentiful food during the long days of summer, but the season is brief and cold weather soon returns. To survive the harsh winter, many animals migrate south, while others hibernate.

Distribution of northern coniferous forests

FORESTS AND LAKES
Coniferous forests often grow on land once covered by ice age glaciers. These glaciers scoured the ground, scraping away soil and creating rounded hills and hollows. When the glaciers melted, the hills became covered with trees and the hollows turned into lakes.

CONIFER LEAVES
Most conifers have small evergreen leaves that are tough enough to withstand the coldest winters. A narrow shape helps the leaves to cope with strong winds.

White spruce

Waterlogged soil beneath trees is acidic and infertile.

Bobcat

PREDATORS
Mammals are relatively scarce in northern forests, so the **predators** that feed upon other animals sometimes have to cover vast distances to find food. Bobcats may roam many miles searching for small prey. Wolves hunt in packs for deer and other large mammals.

Customize for Inclusion Students

Gifted Mammals are not the only animals that hibernate in winter. Many fish, amphibians, and reptiles are also hibernators. Divide students into groups and have each find out how one type of animal hibernates. Have each group explain how that type of hibernation differs from mammal hibernation.

1. A horntail lays eggs deep in a tree trunk.

2. Young larvae bore away from the drill-hole.

3. Each larva matures inside a chamber near the bark of the tree.

EATING WOOD
Several insects of northern forests feed on wood. The horntail, or giant wood wasp, lays eggs by drilling deep beneath tree bark with a long egg-laying tube. The larvae hatch and mature inside the tree while feeding on the wood.

Red crossbill

SEED EATERS
Some birds rely on conifer seeds for food. Crossbill finches have unique bills that are crossed at the tips. This helps them remove seeds from cones. Clark's nutcracker, a member of the crow family, hides 20,000 or more seeds each fall. It is able to remember the locations of many of these seeds for up to nine months.

Spruce cone

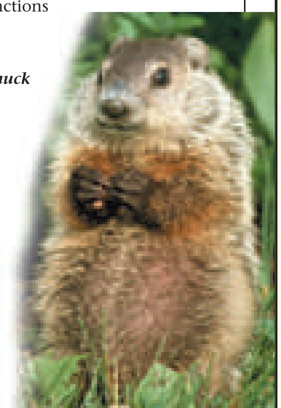
Caribou

ADAPTED FOR TRAVEL
To help them walk across thick layers of snow without sinking, caribou and elk have hooves with broadly splayed toes that help to distribute their weight. Lynx and snowshoe hares have similar adaptations.

Caribou hooves act as snowshoes.

Cold lake water contains few nutrients but is often rich in oxygen.

COPING WITH COLD
To avoid extreme winter temperatures, bears, woodchucks, and other mammals hibernate. During the fall, they build up a store of fat in their bodies that will last until spring. They then go into **hibernation**, which slows their bodily functions to a minimum.



Woodchuck

ASSESSMENT

1. **Key Terms** Define **(a)** coniferous forest, **(b)** predator, **(c)** hibernation.
2. **Climates** Describe the climatic conditions that are generally found in northern coniferous forests.
3. **Ecosystems** How do trees serve as a food source for birds and insects?
4. **Ecosystems** How are mammals of northern coniferous forests well suited for survival in their natural environment?
5. **Critical Thinking** **Developing a Hypothesis** Deforestation has not reduced northern coniferous forests to the same degree that it has reduced mid-latitude deciduous forests. Why do you think that northern coniferous forests have fared better than deciduous forests to the south?

605

Build Science Skills L2

Have students read the introductory paragraph. Ask: **What is the feature that all conifers share?** *(They carry their seeds in cones.)* Then make a list on the board of all the conifers they can name. *(Possible answers: spruce, pine, juniper, cedar, sequoia, redwood, fir, and cypress)* **Logical**

3 ASSESS

Evaluate Understanding L2

Have students create a three-column chart about the types of animals that live in coniferous forests. The columns should be labeled: "Type of Animal," "Feature or Habit," and "How It Promotes Survival." Have students complete the chart using information from the feature. Ask them to write a paragraph describing the plant and animal life in a coniferous forest.

Reteach L1

Have students collect or draw the needles of different kinds of conifers. Then have them write a paragraph that explains how the leaves are well adapted for cold climates. Display collections and paragraphs in the classroom.

Assessment

1. (a) large, dense forests made of trees that carry their seeds in cones; **(b)** animals that feed on other animals; **(c)** a state in which an animal's body functions slow to a minimum for a season
2. Winters are long and cold; summers are brief.
3. Some insects eat wood. Some birds eat conifer seeds.
4. Some mammals, such as elk, have splayed toes that help them walk on snow. Other mammals build up stores of fat during the fall that will last until spring. In winter they hibernate.
5. Sample answer: Fewer people have wanted to settle in cold, northern areas. The land is not suited to farming, so humans have not cut these forests to clear land.

Section 22.1

1 FOCUS

Section Objectives

22.1 **Describe** the contributions of ancient Greeks to astronomy.

22.2 **Compare and contrast** the geocentric and heliocentric models of the solar system.

22.3 **Explain** the contributions to astronomy of Copernicus, Brahe, Kepler, Galileo, and Newton.

Reading Focus

Build Vocabulary L2

Word Origins Explain to students that the prefix *geo-* is a Latin and Greek prefix that means "Earth." *Centric* is from the Greek word *kentrikos*, which means "located in the center." So the word *geocentric* means "having Earth as the center." *Helio-* is a Latin and Greek prefix that means "sun." So the word *heliocentric* means "having the sun as the center."

Reading Strategy L2

a. orbits Earth
b. Aristotle, Ptolemy
c. orbits sun
d. center of universe
e. Aristarchus, Copernicus

2 INSTRUCT

Ancient Greeks

Integrate Social Studies L2

Aristotle was an ancient Greek philosopher and scientist who had a broad range of capabilities. He worked in many areas including physics, chemistry, biology, zoology, botany, psychology, political theory, logic, metaphysics, and philosophy. Have students research the life and works of Aristotle. Encourage students to make an oral presentation to the class. **Verbal**

22.1 Early Astronomy

Reading Focus

Key Concepts

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

Vocabulary

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

Reading Strategy

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

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

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

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

Ancient Greeks

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

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

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

Calculating Earth's Circumference

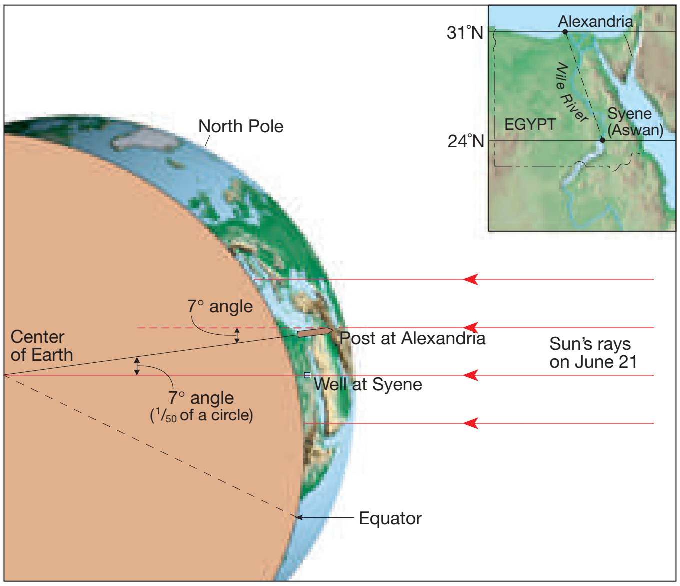


Figure 2 This diagram shows the orientation of the sun's rays at Syene (Aswan) and Alexandria in Egypt on June 21 when Eratosthenes calculated Earth's circumference.

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

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

Go Online SCILINKS NSTA

For: Links on early astronomers
Visit: www.SciLinks.org
Web Code: cjn-7221

Address Misconceptions L2

Some students may confuse astrology and astronomy to the point of thinking that they are the same. *Astronomy* is a scientific probing of the universe to derive the properties of celestial objects and the laws under which the universe operates. *Astrology* is based on ancient superstitions, which explain that an individual's actions and personality are determined by the positions of the planets and stars at the present time, and at the time of the person's birth. Scientists do not accept astrology as a true science. Ask: **Why don't scientists accept astrological beliefs as scientific fact?** *(Astrology is not based on scientific facts or principles. It is based on superstition.)*
Verbal

Build Science Skills L2

Calculating Have students confirm Eratosthenes's calculations of the circumference of Earth and calculate the percent error of the calculation.

$$\frac{7}{360} = \frac{1}{50}$$

5000 stadia × 50 = 250,000 stadia;
if 1 stadia = 157.6 m, then,

$$250{,}000 \text{ stadia} \times \frac{157.6 \text{ m}}{1 \text{ stadia}} =$$

39,400,000 m = 39,400 km;

percent error =

$$\frac{39{,}400 \text{ km} - 40{,}075 \text{ km}}{40{,}075 \text{ km}} \times 100$$

= 1.7%

Eratosthenes's calculation of Earth's circumference is amazing considering this was calculated before 194 B.C.
Logical

Go Online NSTA SCILINKS

Download a worksheet on early astronomers for students to complete, and find additional teacher support from NSTA SciLinks.

Customize for English Language Learners

Encourage English language learners to make a science glossary as they read the section. Students should start with the vocabulary terms and add any other new words they encounter. Have students write brief definitions of each term or draw an illustration that helps them understand the term. Students may want to include definitions in both English and their native language in their glossary.

Section 22.1 (continued)

Use Visuals L1

Figure 3 Have students compare the geocentric and heliocentric models represented in the figure. Ask: **What is the main difference in these two models of the solar system?** *(In the geocentric model, Earth is at the center. In the heliocentric model, the sun is at the center.)* **How do the changing models of the solar system demonstrate the self-correcting nature of science?** *(As new information was discovered about the solar system, the models were changed to incorporate the new information. As more and more information was collected and as technology improved, the model of the solar system became more accurate.)* **Verbal, Portfolio**

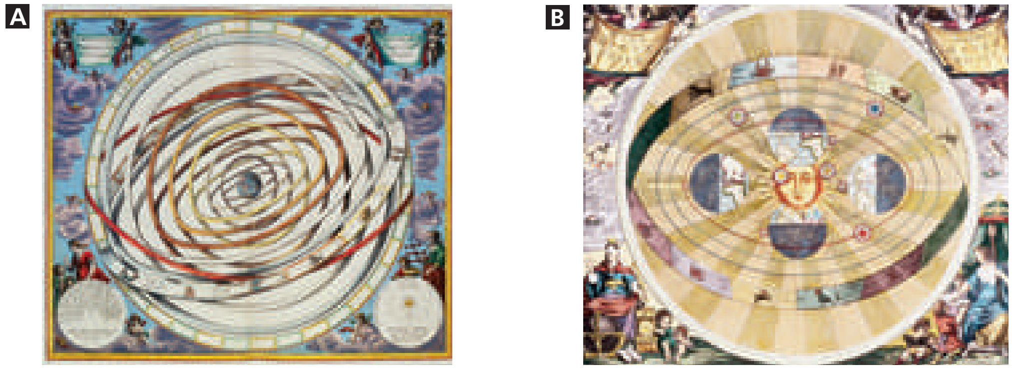


Figure 3 A Geocentric Model of the Universe B Heliocentric Model of the Universe

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

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

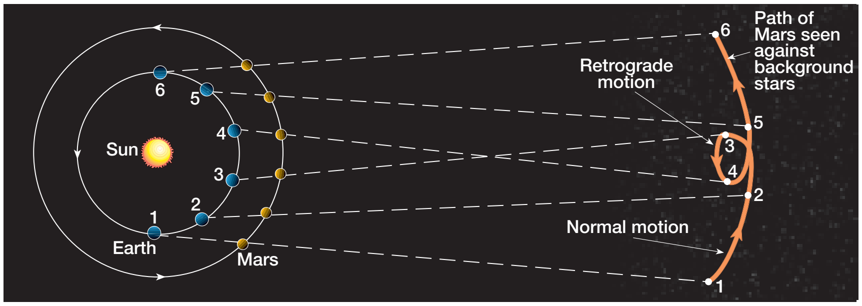
Just like the Greeks, Ptolemy's model had the planets moving in circular orbits around a motionless Earth. However, the motion of the planets against the background of stars seemed odd. Each planet, if watched night after night, moves slightly eastward among the stars. Periodically, each planet appears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

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

Reading Checkpoint ***What is retrograde motion?***

Facts and Figures

Ptolemy's most famous work was a 13-volume text written in Greek called *He mathematike syntaxis*, or *The Mathematical Collection*. This great work was translated into Arabic by Arab scholars and renamed *al-Majisti,* or *Great Work*. The book is now known as the *Almagest*. In this work, Ptolemy used mathematical terms to explain the motions of the heavenly bodies. Ptolemy's explanations of the planets' movements were widely accepted.



The Birth of Modern Astronomy

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

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

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

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

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

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

The Birth of Modern Astronomy

Use Visuals

L1

Figure 4 To help students understand the concept of retrograde motion, have them trace the eye's line of sight with their finger. Tell students to find the number 1 in the left part of the diagram and follow the dotted line to the position of Mars. Then have students repeat this process for each numbered position.

Ask: **Why does Mars appear to have retrograde motion?** *(Earth has a faster orbital speed than Mars has and overtakes it.)* **Using Newton's laws of motion, explain why retrograde motion is impossible.** *(Mars would not reverse its direction of motion unless it was acted upon by an outside force that would change its direction. Inertia and gravity will keep it moving in a forward direction.)*
Visual

Address Misconceptions

L2

Some students may think that modern astronomy was developed recently by a small number of scientists. The body of astronomical knowledge is an accumulation of work by many scientists over many centuries of time. Modern astronomers study the works of earlier scientists and build on the foundation of knowledge that they have laid. In fact, Sir Isaac Newton has been quoted as saying, "If I have seen further, it is by standing on the shoulders of giants."
Ask: **What is an example of a field of science that does not contain an accumulation of knowledge that was acquired over many years?** *(There is no such field of science. All fields of science are accumulations of knowledge.)*
Verbal

Facts and Figures

The Copernican explanation of the solar system challenged the belief that Earth was the center of the universe and was considered heretical by the Roman Catholic Church. Copernicus's text, *De Revolutionibus, Orbium Coelestium (On the Revolution of the Heavenly Spheres)*, was published as he lay on his deathbed in 1543. One of Copernicus's followers, Giordano Bruno, was seized in 1600 during the Inquisition, a Roman Catholic tribunal for the discovery and punishment for heresy. He refused to denounce the Copernican theory and was burned at the stake.

Answer to . . .

Reading Checkpoint *Retrograde motion is the apparent westward drift of a planet resulting from the combination of the motion of Earth and the planet's own motion around the sun.*

Teacher Demo

Visualizing an Astronomical Unit L2

Purpose Students will make a model showing the distances between the planets.

Materials several rolls of adding machine tape, meter sticks, tape, Table 1 from p. 618 of the student text

Procedure Have students mark off the distance each planet is from the sun using adding machine tape. Tell students to use one meter to represent ten astronomical units. Students may have to stretch the tape down a long hallway to view the entire tape at once.

Expected Outcome Students will observe the distance relationships between the planets by making a model.

Kinesthetic, Logical

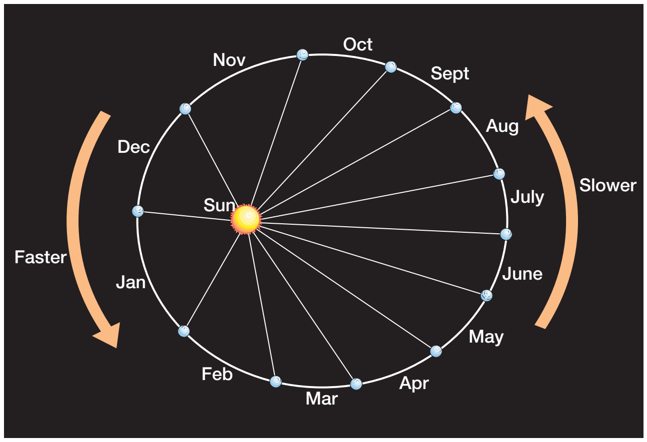


Figure 6 Planet Revolution
A line connecting a planet to the sun would move in such a manner that equal areas are swept out in equal times. Thus, planets revolve slower when they are farther from the sun and faster when they are closer.

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

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

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

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

Using these units, Kepler's third law states that the planet's orbital period squared is equal to its mean solar distance cubed ($P^2 = a^3$). Therefore, the solar distances of the planets can be calculated when their periods of revolution are known. For example, Mars has a period of 1.88 years, which squared equals 3.54. The cube root of 3.54 is 1.52, and that is the distance to Mars in astronomical units shown in Table 1.

Table 1 Period of Revolution and Solar Distances of Planets

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

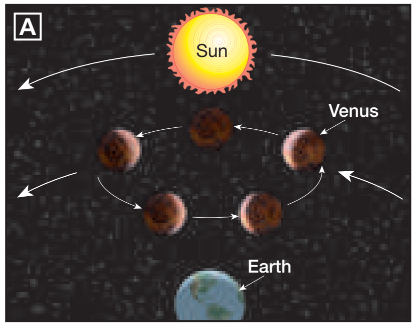
*AU = astronomical unit.

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

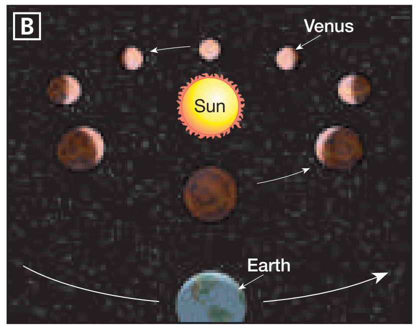
Using the telescope, Galileo was able to view the universe in a new way. He made many important discoveries that supported Copernicus's view of the universe, such as the following:

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

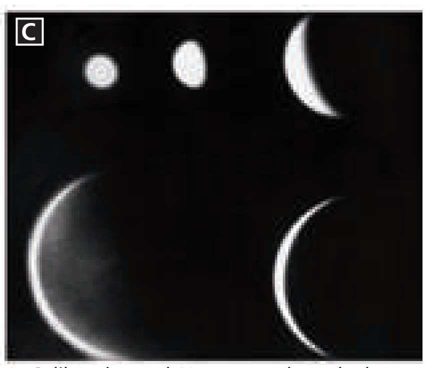
The Solar System Model Evolves



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



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



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

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

Build Reading Literacy

L1

Refer to **p. 612D,** which provides the guidelines for thinking aloud.

Think Aloud Set the example for this strategy by verbalizing your own thought processes while reading about "Galileo Galilei." Encourage students to read "Sir Isaac Newton" while quietly verbalizing their thought processes. Then have a class discussion about the advantages students found in staying focused on a logical thought process when reading in this manner.
Intrapersonal, Auditory

Facts and Figures

The Roman Catholic Church continued to try to control the work of scientists during Galileo's time. In 1616, the Church condemned the Copernican theory and told Galileo to abandon it. Galileo refused and wrote his most famous work, *Dialogue of the Great World Systems*. After it was published, critics pointed out that Galileo was promoting the Copernican view of the solar system. Galileo was called before the Inquisition. He was tried and convicted of proclaiming doctrines contrary to religious doctrine and was sentenced to permanent house arrest. He lived the last ten years of his life under house arrest.

Answer to . . .

Figure 7 *only the crescent phase*

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Section 22.1 (continued)

Teacher Demo

A Simple Mirror Telescope

L2

Purpose Students will observe how a mirror telescope works.

Materials lightbulb in a lamp base, magnifying lens, mirror with concave surface (magnifying mirror with 2 sides—used for makeup and shaving)

Procedure Place the light on a table in a darkened room. Turn the light on and use the concave surface of the mirror to reflect the lightbulb on the wall. Move the mirror until you get a sharp image on the wall. Observe the image of the bulb on the wall through the magnifying glass. Move the magnifying glass to get the largest and clearest image.

Expected Outcome Students will observe how a mirror telescope enlarges an image to make it easier to study. **Kinesthetic, Visual**

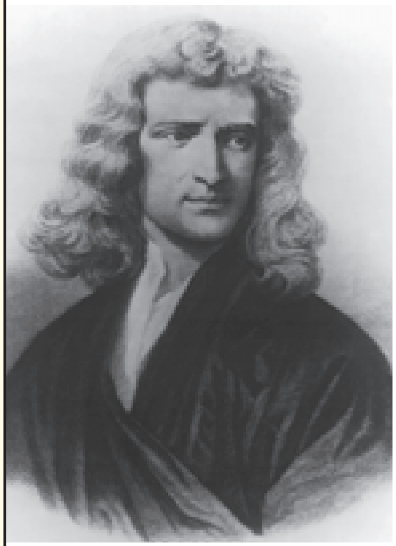


Figure 8 Sir Isaac Newton

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

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

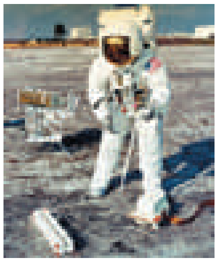
Universal Gravitation According to Newton, every body in the universe attracts every other body with a force that is directly proportional to their masses and inversely proportional to the square of the distance between their centers of mass.

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

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

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

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



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

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

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

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

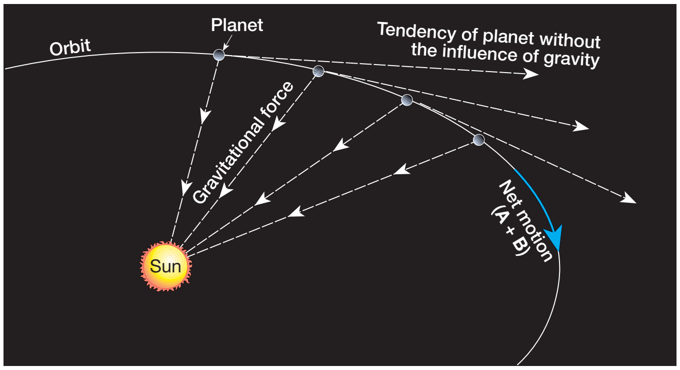


Figure 10 Without the influence of gravity, planets would move in a straight line out into space.

Section 22.1 Assessment

Reviewing Concepts

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

Critical Thinking

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

Math Practice

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

3 ASSESS

Evaluate Understanding

L2

Have students write three review questions for this section. Students should then work in small groups and ask one another their questions.

Reteach

L1

Use Figures 3 and 4 to review geocentric and heliocentric models of the solar system.

Math Practice

Solutions

7. $P^2 = a^3$

$5^2 = 2.9^3$

$10^2 = 4.6^3$

$\frac{10}{365}^{2} = 0.09^3$

Section 22.1 Assessment

1. In the geocentric model, the sun and planets revolve around Earth. In the heliocentric model, Earth and the other planets revolve around the sun.
2. Retrograde motion occurs when Earth, which travels faster than Mars, passes Mars. This makes Mars appear to go westward.
3. Ptolemy showed planets moving in circular orbits around Earth.
4. Copernicus placed the sun at the center of the solar system. This was a major break from the ancient idea that Earth lies at the center.
5. Sample answer: The telescope allowed Galileo to view the universe in a new way, leading to many discoveries on his part.
6. The path of a planet around the sun is an ellipse. Each planet revolves so that an imaginary line connecting it to the sun sweeps over equal areas at equal time intervals. The squares of the orbital periods of the planets to the cubes of their average distances from the sun.

Answer to . . .

Figure 9 *325.6 N*

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Section 22.2

1 FOCUS

Section Objectives

22.4 **Describe** the movements of Earth known as rotation, revolution, and precession.
22.5 **Explain** how the moon goes through phases.
22.6 **Explain** how eclipses occur.

Reading Focus

Build Vocabulary L2

Word-Part Analysis List on the board the following word parts and meanings: *helios*, "sun"; *ge* or *gee*, "earth"; *peri-*, "around or near"; *ap-* or *apo-*, "away from." Have students identify these word parts in the vocabulary terms. Discuss the terms' meanings with students.

Reading Strategy L2

a. Earth comes between the moon and sun.
b. solar eclipse.
c. lunar eclipse.

2 INSTRUCT

Motions of Earth

Integrate Language Arts L2

Archaeologists believe that Stonehenge was built in three stages between about 3000 to 1000 B.C. Stonehenge was probably used as a religious center or a type of astronomical clock or calendar. Have students research information on the construction and possible purposes for Stonehenge. Students should prepare a short report and make a visual aid showing the layout of Stonehenge.
Verbal, Portfolio

22.2 The Earth-Moon-Sun System

Reading Focus

Key Concepts

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

Vocabulary

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

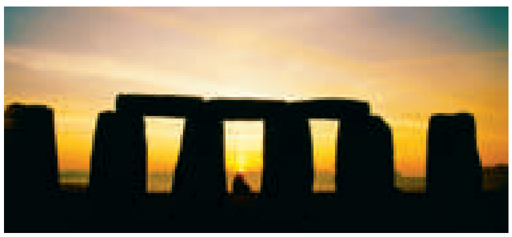
Reading Strategy

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

Eclipses occur when
- the moon comes between Earth and the sun. → Such an event is called a → b. ?
- a. ? → Such an event is called a → c. ?

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

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



Motions of Earth

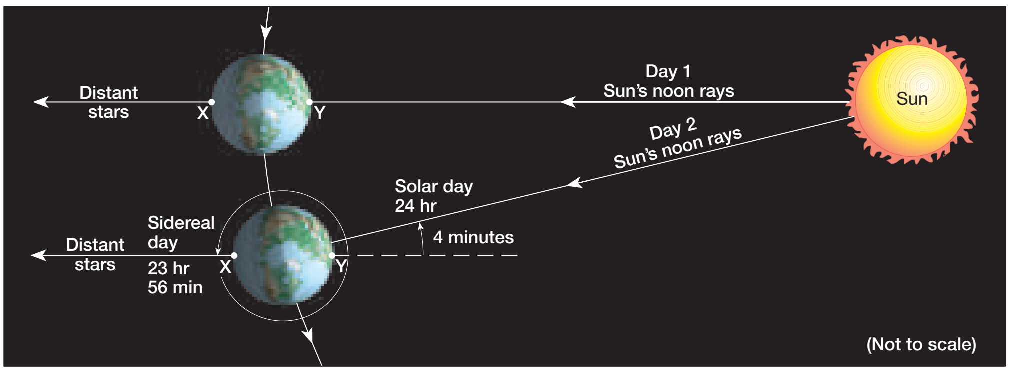
The two main motions of Earth are rotation and revolution. Rotation is the turning, or spinning, of a body on its axis. **Revolution** is the motion of a body, such as a planet or moon, along a path around some point in space. For example, Earth revolves around the sun, and the moon revolves around Earth.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

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

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

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

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



Use Visuals L1

Figure 12 Have students examine the movement of Earth and the locations of points X and Y carefully. Ask: **What are the reference points for a mean solar day and a sidereal day?** *(A mean solar day is measured using the sun as a reference point. A sidereal day is measured using a star other than the sun as a reference point.)* **Why do these two reference points give two different results?** *(The direction from Earth to a distant star barely changes, but the distance from Earth to the sun changes by almost one degree each day.)* **Why do astronomers choose to use the sidereal day instead of the mean solar day?** *(The stars appear in the same position in the sky every 24 sidereal hours.)*
Visual, Logical

Customize for English Language Learners

Have students draw simple illustrations for the motions of Earth, the motions of the Earth-moon-sun system, and eclipses. Have them explain each illustration to a partner. Then have each pair of students discuss why the motions occur as they do.

Build Reading Literacy L1

Refer to **p. 334D** in **Chapter 12,** which provides the guidelines for outlining.

Outline Have students read the text on pp. 622–629 relating to the Earth-moon-sun system. Then ask students to use the headings as major divisions in an outline. Suggest that students refer to their outlines when answering the questions in the Section 22.2 Assessment.
Verbal

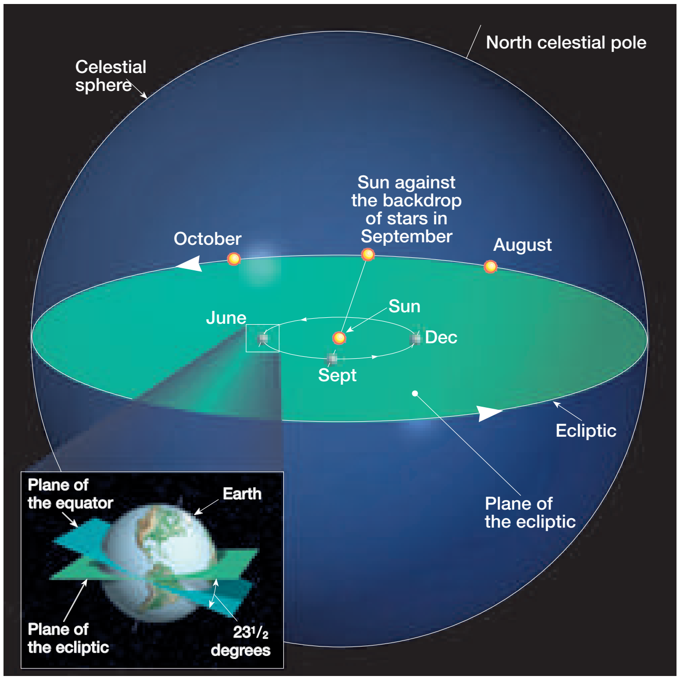


Figure 13 The Ecliptic Earth's orbital motion causes the apparent position of the sun to shift about 1 degree each day on the celestial sphere.

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

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

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

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

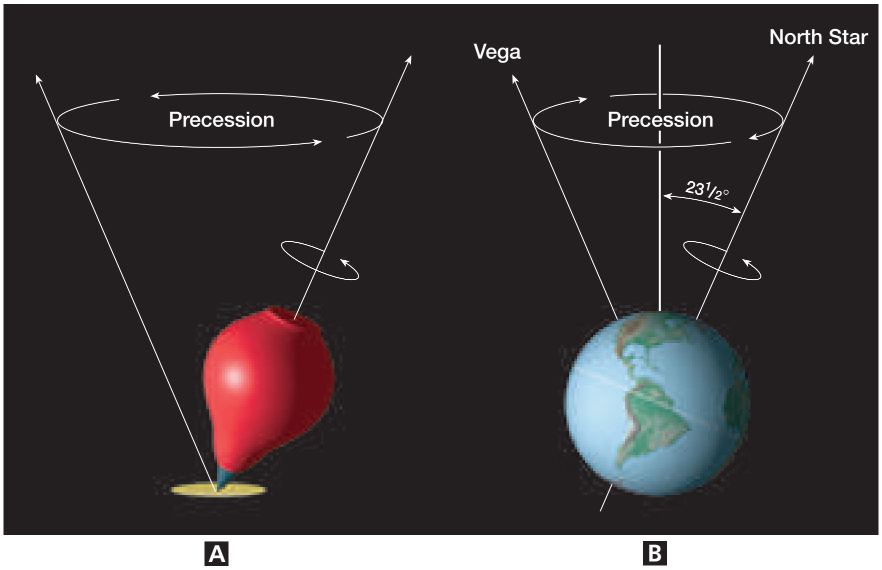


Figure 14 Precession
A Precession is similar to a spinning top. It causes the North Pole to point at different parts of the sky during a 26,000-year cycle. **B** Today, the North Pole points to Polaris.
Interpreting Illustrations ***What star will the North Pole point to in 13,000 years?***

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

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

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

Reading Checkpoint *What is precession?*

Teacher Demo

Observing Precession L2

Purpose Students will observe the precession of a toy top.

Materials a toy top similar to the one shown in Figure 14

Procedure Put a distinctive mark on the top of the top where the axis of rotation is located. This will give students a specific point to observe. Put the top in motion. Have students observe the precession of the top.

Expected Outcome Students will observe an object in precession, which is similar to Earth's motion.
Visual

Answer to . . .

Figure 14 *Vega*

Reading Checkpoint *Precession is the slow movement of Earth's axis over a period of 26,000 years.*

Motions of the Earth-Moon System

Build Science Skills

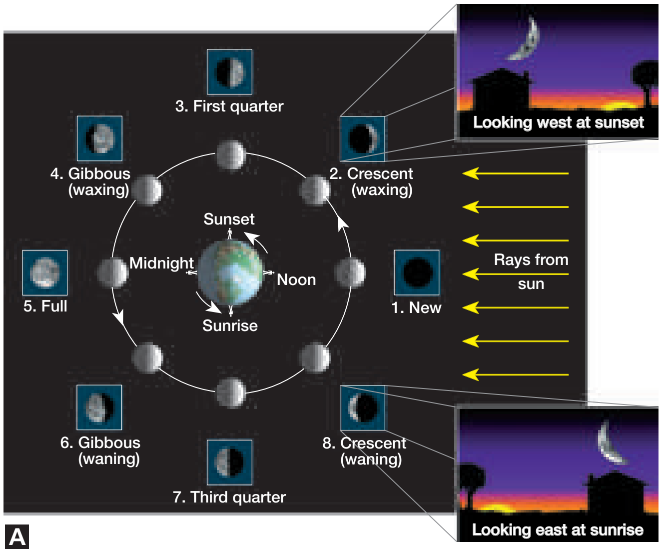
L2

Interpreting Diagrams/ Photographs Compare the photographs at the bottom of the page, Figure 15B, with those in Figure 15A. Ask students to label the photographs with the phase of the moon that is shown from left to right. *(Crescent, waning; Third quarter; Gibbous, waning; and Full.)* Challenge students to recognize the patterns for a waxing and waning moon. *(When the right side of the moon is lit, the moon is in its waxing phase. When the left side is lit, the moon is waning.)*
Visual, Logical

Address Misconceptions

L2

Students may have four different misconceptions of why the moon goes through phases. (1) Clouds cover part of the moon. (2) Planets cast a shadow on the moon. (3) The shadow of the sun falls on the moon. (4) The shadow of Earth falls on the moon. Help students realize that lunar phases are a result of the motion of the moon and the sunlight that is reflected from its surface.
Logical



Motions of the Earth-Moon System

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

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

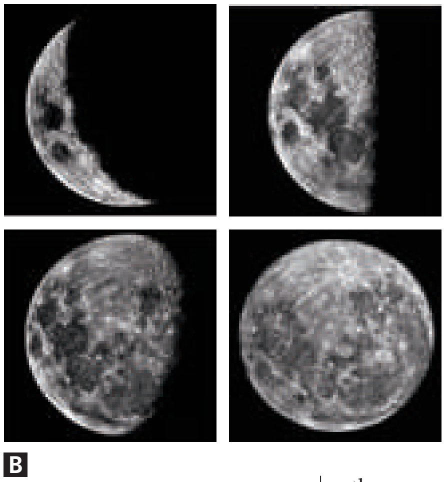


Figure 15 Phases of the Moon
A The outer figures show the phases as seen from Earth.
B Compare these photographs with the diagram.

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

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

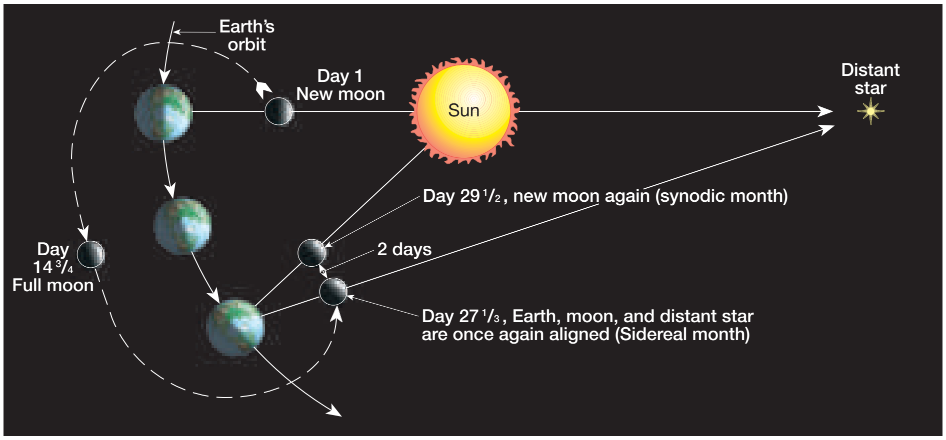


Figure 16 Lunar Motion As the moon orbits Earth, the Earth-moon system also moves in orbit around the sun. Thus, even after the moon makes one revolution around Earth, it has not yet reached its starting point in relation to the stars.

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

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

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

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

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

Q&A

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

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

Use Visuals L1

Figure 16 Have students examine this figure. Ask: Why do the synodic and sidereal month differ? *(The moon makes a complete orbit around Earth in 27 1/3 days, as viewed from a distant star. It takes the moon 29 1/2 days to go through its phases.)* **What is the reference point for the sidereal month?** *(A distant star)* **For the synodic month?** *(The sun)*
Visual

Integrate Social Studies L2

The calendar that we use today was devised in 45–44 B.C. by Julius Caesar and is known as the Julian calendar. Have students research to find the basis of the modern calendar. Ask students to define a year, month, week, and day. Encourage students to find out the traditions that were adopted when devising this calendar. Have students prepare a report on the history of the modern calendar.
Verbal, Portfolio

Facts and Figures

Ancient calendars were based on phases of the moon. The month was originally defined as the time between two full moons, or 29 1/2 days. The lunar calendar year was 354 days, which is 11 1/4 days short of a solar year.

An additional month was occasionally added to lunar calendars to align the calendar with the seasons. Ancient Egyptians were the first to devise a calendar based on a solar year.

Answer to . . .

Reading Checkpoint *The moon's period of rotation about its axis and its revolution around Earth are the same.*

Eclipses

Use Community Resources

L2

Arrange for your class to visit a planetarium. Have students prepare questions regarding the topics in this chapter in advance.
Interpersonal

Use Visuals

L1

Figure 17A Have students examine this figure. Ask: **During a solar eclipse, why do observers in the umbra see a total solar eclipse?** *(The moon completely blocks the sun from the viewer.)* **Why do observers in the penumbra see a partial eclipse?** *(The moon only partially blocks the sun from the viewer.)*

Figure 17B Have students examine this figure. Ask: **When does a total lunar eclipse occur?** *(A total lunar eclipse occurs when Earth completely blocks the moon from the sun and the moon is completely in Earth's shadow.)* **When does a partial lunar eclipse occur?** *(A partial lunar eclipse occurs when Earth partially blocks the moon from the sun and only a portion of the moon is in Earth's shadow.)*
Visual, Logical

Go Online NSTA SciLinks

Download a worksheet on eclipses for students to complete, and find additional teacher support from NSTA SciLinks.

Go Online SciLinks NSTA

For: Links on eclipses
Visit: www.SciLinks.org
Web Code: cjn-7222

Eclipses

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

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

Solar and Lunar Eclipse

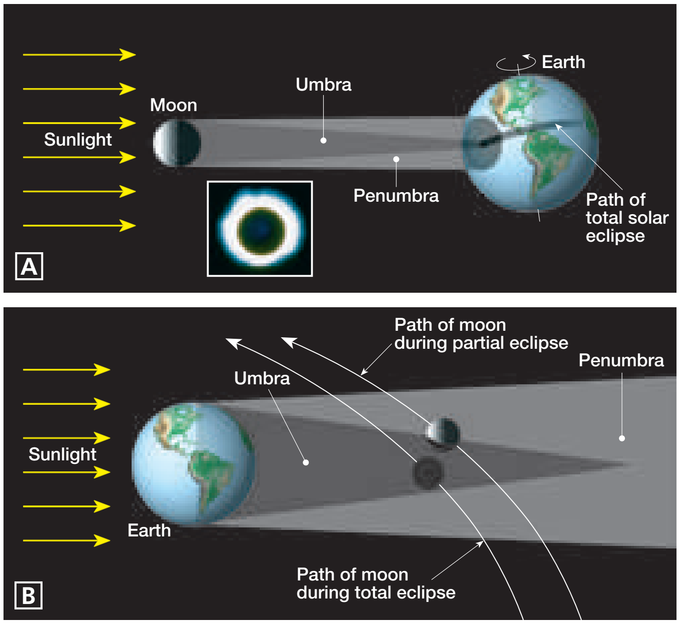


Figure 17 A Observers in the umbra see a total solar eclipse. Those in the penumbra see a partial eclipse. The path of the solar eclipse moves eastward across the globe. The figure shows a total solar eclipse. **B** During a total lunar eclipse, the moon's orbit carries it into Earth's umbra. During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

Facts and Figures

One of the earliest surviving records of eclipse observations is from ancient China. Astronomers recorded their observations from 722 to 481 B.C. in a chronicle called *Ch'un-ch'iu (Spring and Autumn Annals)*. As many as 32 of the eclipses recorded in the *Ch'un-ch'iu* can be identified by modern calculations.

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

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

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

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

Section 22.2. Assessment

Reviewing Concepts

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

Critical Thinking

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

Writing in Science

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

3 ASSESS

Evaluate Understanding L2

Call out different phases of the moon. Have students draw the phases on the board or in their notebooks.

Reteach L1

Write *rotation, revolution,* and *precession* on the board. Have students quiz each other on these motions of Earth.

Writing in Science

Students should choose one of the astronomers and include factual details in their paragraphs. An example might be Copernicus, whose heliocentric view changed the way people viewed the universe. Paragraphs should be written from the first-person point of view.

Section 22.2 Assessment

1. Earth revolves around the sun, rotates on its axis, and moves slightly on its axis. It also revolves with the solar system around the Milky Way.
2. rotation: day and night; revolution: seasons
3. the motion of the moon and the amount of sunlight reflected from its surface that can be seen from Earth
4. The left edge of the moon is visible during the crescent phase that precedes the new moon, while the right side of the moon is visible during the crescent phase that follows the new moon.
5. The moon's orbit must cross the plane of the ecliptic for an eclipse to take place.
6. During a solar eclipse, the moon is between the sun and Earth. During a lunar eclipse, Earth is between the sun and moon.
7. Sample answer: The difference between perihelion and aphelion has little influence on the quantity of radiation received by Earth. The primary cause of seasons is Earth's tilted axis, not its distance from the sun. So any changes in summer or winter temperatures would be small. The overall impact on the biosphere and hydrosphere would also be small.

Section 22.3

1 FOCUS

Section Objectives

22.7 **Describe** how the physical features of the lunar surface were created.

22.8 **Explain** the history of the moon.

Reading Focus

Build Vocabulary L2

Vocabulary Rating Chart Have students construct a chart with four columns labeled Term, Can Define or Use It, Heard or Seen It, and Don't Know. Have students copy the terms *crater*, *ray*, *mare*, *rille*, and *lunar regolith* into the first column and rate their term knowledge by putting a check in one of the other columns. Ask how many students actually know each term. Have them share their knowledge. Ask focused questions to help students predict text content based on the term, thus enabling them to have a purpose for reading. After students have read the section, have them rate their knowledge again.

Reading Strategy L2

a. Huge quantities of crust and mantle were ejected into space.
b. The debris began orbiting Earth.
c. Debris united to form the moon.

22.3 Earth's Moon

Reading Focus

Key Concepts

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

Vocabulary

- crater
- ray
- mare
- rille
- lunar regolith

Reading Strategy

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

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

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

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

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

The Lunar Surface

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

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

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

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

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

Formation of a Crater

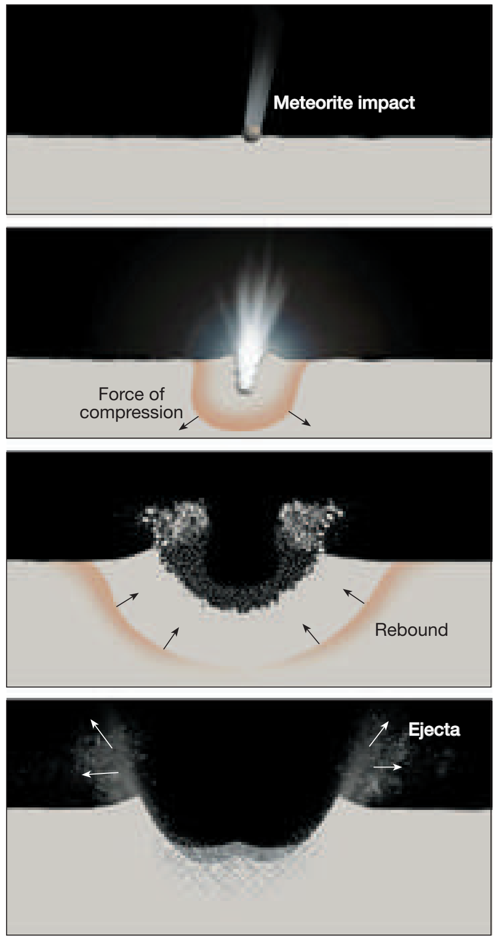


Figure 19 The energy of the rapidly moving meteoroid is transformed into heat energy. Rock compresses, then quickly rebounds. The rebounding rock causes debris to be ejected from the crater.

2 INSTRUCT

The Lunar Surface

Build Reading Literacy L1

Refer to **p. 306D** in **Chapter 11,** which provides the guidelines for KWL (Know/Want to Know/Learned) charts.

KWL Teach this independent study skill as a whole-class exercise.

1. Draw a three-column KWL chart on the board for students to copy.
2. Have students complete the Know column with facts, examples, and other information that they already know about the lunar surface.
3. Tell students to complete the Want to Know column with questions about the moon's surface.
4. Have students read pp. 631 and 632 about the moon. As they read, have them note answers to their questions in the Learned column, along with facts, examples, and details they learned.
5. Have students draw an Information I Expect to Use box below their KWL chart. Have them review the information in the Learned column and categorize the useful information in the box.
Verbal

Customize for Inclusion Students

Visually Impaired Have students with visual impairments feel the topography of the moon, using a relief globe or map of the moon. Assign visually-impaired students a partner to guide their fingers and to read the map or globe for them. Discuss with students what they have discovered about the surface of the moon.

Origin of Modern Astronomy 631

Build Science Skills

L2

Using Models

ACTIVITY

Purpose Students will model the surface features of the lunar surface.

Materials foam poster board; soft modeling clay; toothpicks; narrow paper strips; tape; pencil, pen, or marker

Class Time 30 minutes

Procedure Have students use Figure 20 as a guide for their topographic map. First, instruct students to draw the physical features on the foam poster board. Next, have students use the soft modeling clay to build the surface features. Then students should create flag-type labels for the physical features, using narrow strips of paper, toothpicks, and tape. Finally, have students use the markers to identify the physical features on the surface of their topographical map.

Expected Outcome Students learn the major topographical surface features on the lunar surface.
Visual, Kinesthetic

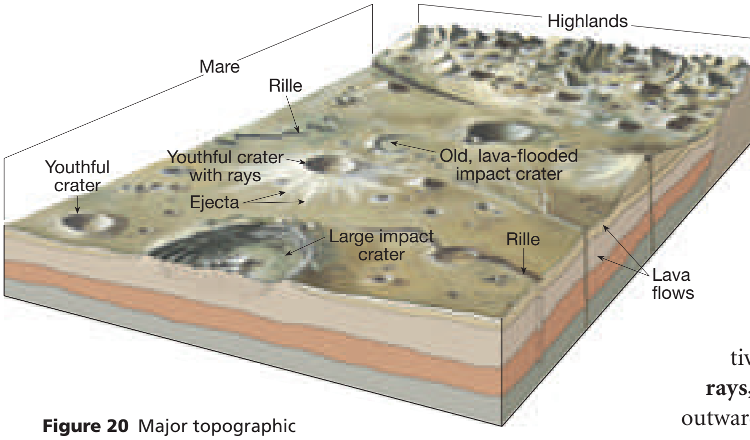


Figure 20 Major topographic features on the moon's surface include craters, maria, and highlands.
Identifying ***Where are rilles located?***

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

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

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

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

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

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

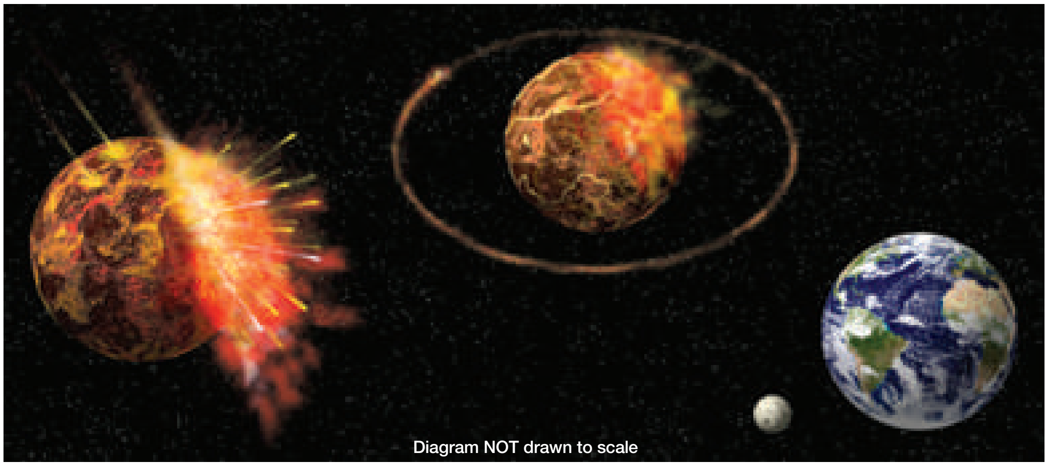


Figure 21 The moon may have formed when a large object collided with Earth. The resulting debris was ejected into space. The debris began orbiting around Earth and eventually united to form the moon.

Lunar History

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

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

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

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

Lunar History

Integrate Language Arts L2

Much of the scientific information that is known about the composition of the lunar surface is due to the Apollo Space Program. Have students research the scientific discoveries that were made as a result of this program. Students should prepare a presentation about the information they have learned. If possible, encourage students to make a computer presentation that includes actual photographs from the various missions.
Verbal, Portfolio

Use Visuals L1

Figure 21 Have students study this figure. Ask: **What evidence suggests that the moon came from mostly iron-poor mantle and crustal rocks from Earth?** *(The lack of a sizeable iron core on the moon)* **Why doesn't this ejected material contain water?** *(The material has been in orbit long enough to have lost any water that it may have had.)*
Verbal

Facts and Figures

The United States was not the only country with a space program. The former Union of Soviet Socialist Republics also had one. In fact, the U.S.S.R. was the first country to launch an artificial Earth satellite, *Sputnik 1*, in 1957. In early 1959, the Soviet spacecraft, *Luna 1*, became the first artificial object to orbit the sun. Later in 1959, *Luna 2* crashed into the moon to become the first artificial object on the lunar surface. Also in 1959, *Luna 3* took the first pictures of the moon's far side. The Soviet goal to send the first crewed spacecraft to the moon was never realized. In 1969, the United States became the first country that safely landed a person on the moon.

Answer to . . .

Figure 20 *Rilles are associated with maria.*

Reading Checkpoint *a soil-like layer of igneous rocks, glass beads, and fine lunar dust*

Section 22.3 (continued)

3 ASSESS

Evaluate Understanding L2

Have students make flashcards on the details found in this section. Tell students to write a question on one side of the card and the answer on the other. Students can use these flashcards to quiz each other in class.

Reteach L1

Write the headings *Lunar Surface* and *Lunar History* on the board. Ask students to give you facts from the section about each topic. Write the information under the appropriate heading. Students can copy this information from the board and use it as a study aid.

Connecting Concepts

Scientists observe variations in crater density. They also analyze material gathered from space missions.

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

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

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

Section 22.3 Assessment

Reviewing Concepts

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

Critical Thinking

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

Connecting Concepts

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

Section 22.3 Assessment

1. Craters form from the impact of rapidly moving debris.
2. when asteroids punctuated the lunar surface, letting magma bleed out
3. A Mars-sized object collided with Earth. Huge quantities of crust and mantle were ejected into space. The debris began orbiting Earth and eventually united to form the moon.
4. Of the four spheres, the atmosphere, hydrosphere, and biosphere are absent, or nearly absent, on the moon. Because the moon lacks these spheres, processes such as chemical weathering, erosion, soil formation, weather in general, and sedimentation are all absent.
5. Erosion and subduction have removed most craters from Earth's surface.

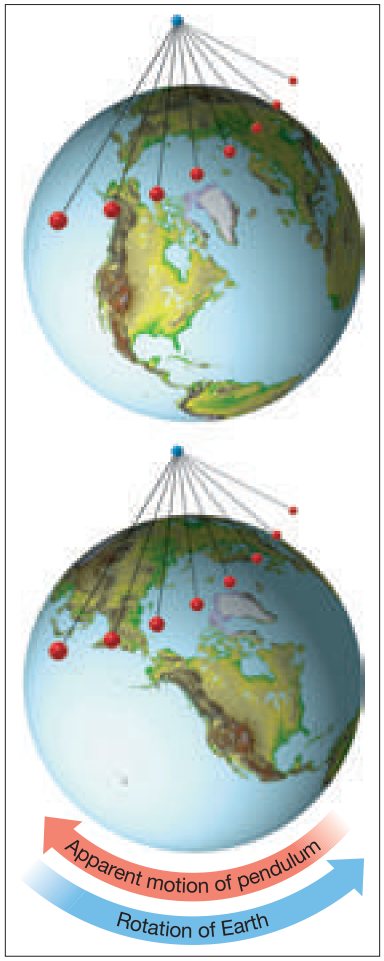
understanding EARTH

Foucault's Experiment

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

The Swinging Pendulum

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



Evidence of Earth's Rotation

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

understanding EARTH

Foucault's Experiment L2

Background

The Foucault pendulum was constructed in 1851 by Jean Bernard Foucault and was demonstrated for the first time at the world's fair in Paris. The pendulum consisted of a 28-kg iron ball suspended from the dome of the Pantheon by a 67-m long steel wire.

Teaching Tips

After students have read p. 635, ask: **Once the pendulum is set in motion, it will continue to swing in the same direction unless it is pushed or pulled by a force. Why is this true?** *(The pendulum's motion will obey Newton's first law of motion.)*

What outside force is acting on the pendulum? *(There is no outside force acting on the pendulum.)*

Why does the pendulum change position over time? *(The pendulum did not change position, Earth moved beneath the pendulum.)*

How does this prove that Earth is rotating? *(The pendulum continued moving in the same direction because no outside force acted upon it. Since the pendulum did not change its motion, Earth beneath it must be moving.)* **Verbal**

1 FOCUS

Section Objectives

23.1 **List** the major differences between the terrestrial and Jovian planets.

23.2 **Explain** how the solar system formed.

Reading Focus

Build Vocabulary L2

Word Part Analysis Teach students that *terr-* means "Earth," and *-ial* and *-ian* mean "of, or related to" so *terrestrial* means "Earthly" or "Earth-like." Terrestrial planets are those similar to Earth while Jovian planets are those similar to Jupiter.

Advise students that *nebula* is related to the word *nebulous*, which means "hazy" or "unclear." The word *nebula* is used to describe a "hazy mass of gases and dust seen among the stars." Tell students that *infinitesimal* means "infinitely small," and have them predict the meaning of *planetesimal*. *(Planetesimals are small solid bodies that combine to form planets.)*

Reading Strategy L2

a. The sun formed at the center of a disk.
b. Matter collided to form planetesimals.
c. Planetesimals eventually grow into planets.

2 INSTRUCT

Use Visuals L1

Figure 1 This diagram shows the orbits of all 9 planets around the sun. Ask: **Which planet is the closest to the sun?** *(Mercury)* **The asteroid belt is found between which two planets?** *(Mars and Jupiter)*

Direct students to observe the scale along the bottom of the figure that shows the scale distances from planet to planet. Tell students that the inner planets are those found before the asteroid belt, and the outer planets are found after the asteroid belt. Ask: **How does the distance between the inner planets differ from the distance between the outer planets?** *(The inner planets are much closer together than the outer planets.)*
Visual

23.1 The Solar System

Reading Focus

Key Concepts

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

Vocabulary

- terrestrial planet
- Jovian planet
- nebula
- planetesimal

Reading Strategy

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

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

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

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

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

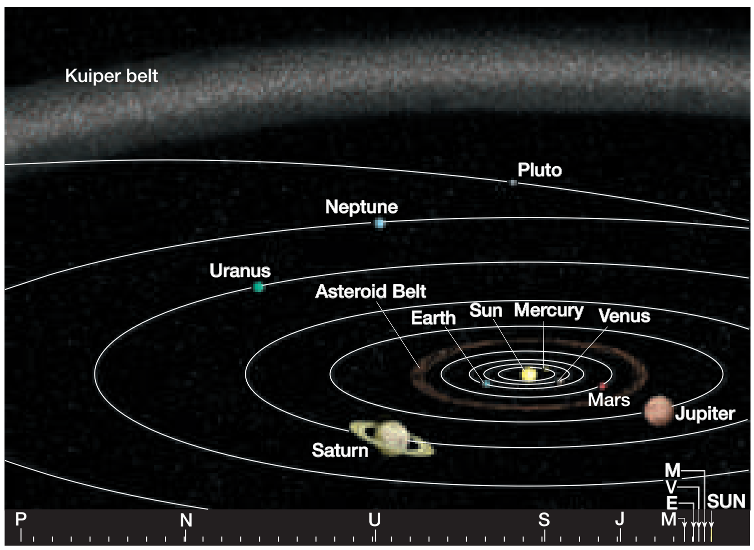


Figure 1 Orbits of the Planets The positions of the planets are shown to scale along the bottom of the diagram.

The Planets: An Overview

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

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

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

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

Table 1 Planetary Data

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

*Includes all satellites discovered as of March 2004.

The Planets: An Overview

Build Reading Literacy L1

Refer to **p. 642D**, which provides guidelines for this reading strategy.

Compare and Contrast Have students create a chart comparing the characteristics of the terrestrial planets and the Jovian planets. Have them start with what they observed about the distances between planets in the **Use Visuals** activity on p. 644, and use the reading, tables, and figures on pp. 645–647. For example:

Terrestrial Planets	Jovian Planets
Orbits are close together	Orbits are far apart
Smaller diameter	Larger diameter
More dense	Less dense
Rotate slower	Rotate faster
Thin or no atmosphere	Thick atmosphere
Composed mostly of rocky and metallic substances, with few gases and ices	Mostly made of gases and ices, but with rocky and metallic materials in their cores

Visual, Verbal

Customize for Inclusion Students

Learning Disabled Help students complete Compare and Contrast activities by providing them with scaffolding. Give them a chart to fill in that lists the categories they should be comparing. For example, these students could be given a chart such as the one below to use for the Compare and Contrast activity on this page.

Characteristic	Terrestrial Planets	Jovian Planets
Distance from one planet to the next		
Diameter		
Density		
Rotation rate		
Atmosphere		
Composition		

Answer to . . .

Reading Checkpoint *The terrestrial planets have greater densities than the Jovian planets.*

Use Visuals

L1

Figure 2 Have students study Figure 2 and answer the caption question. Ask: **Which planet is the smallest?** *(Pluto)* **Which planet is the largest?** *(Jupiter)* **How does the size of the largest planet compare to the size of the sun?** *(Jupiter is much smaller than the sun.)*
Visual

Address Misconceptions

L2

Many students think that the solar system and outer space are very crowded. Help students overcome this misconception by using Table 1 Planetary Data. Have students look at the column describing the distance from the sun. Point out to them that the distances are given in *millions* of kilometers. Tell students that if they chose a point in the solar system at random, it is unlikely it would be near a planet.
Visual, Verbal

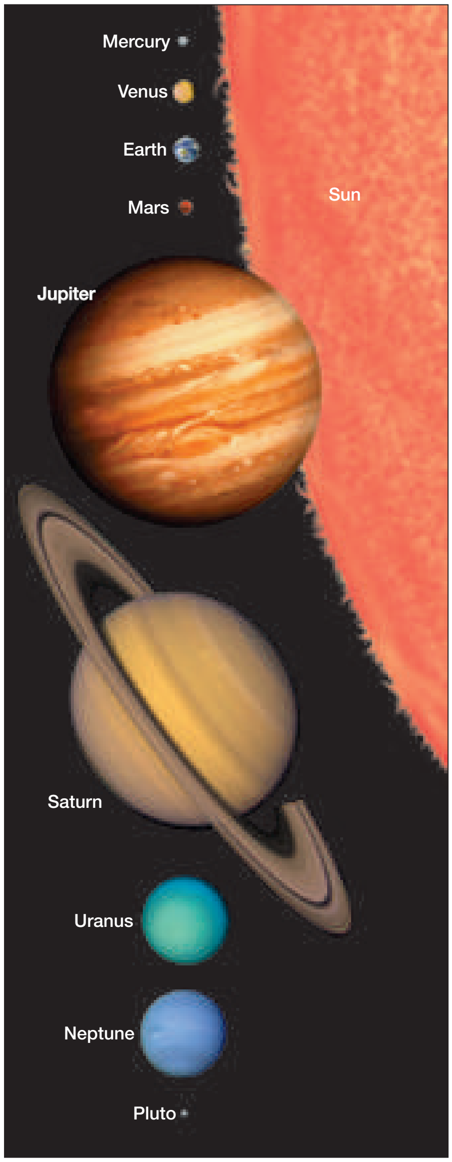


Figure 2 The planets are drawn to scale.
Interpreting Diagrams ***How do the sizes of the terrestrial planets compare with the sizes of the Jovian planets?***

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

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

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

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

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

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

Facts and Figures

Why are the Jovian planets so much larger than the terrestrial planets? According to the nebular hypothesis, the planets formed from a rotating disk of dust and gases that surrounded the sun. The growth of planets began as solid bits of matter began to collide and clump together. In the inner solar system, the temperatures were so high that only the metals and silicate materials could form solid grains. It was too hot for ices of water, carbon dioxide, and methane to form. Thus, the innermost (terrestrial) planets grew mainly from the high melting point substances found in the solar nebula. By contrast, in the frigid out reaches of the solar system, it was cold enough for ices of water and other substances to form. Consequently, the outer planets are thought to have grown not only from accumulations of solid bits of metals and silicate minerals but also from large quantities of ices. Eventually, the outer planets became large enough to gravitationally capture the lightest gases (hydrogen and helium), and thus grow to become "giant" planets.

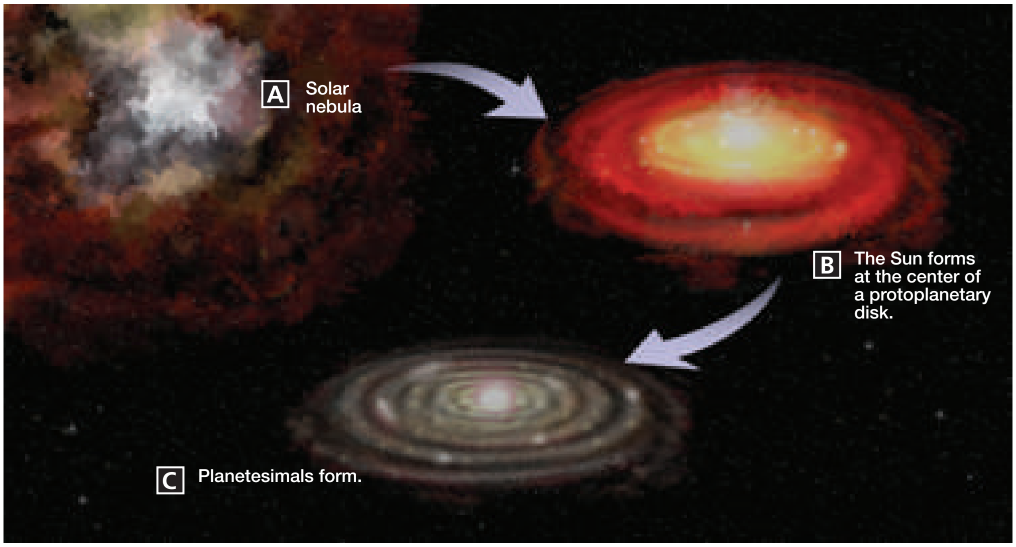
In contrast, the Jovian planets have much greater surface gravities. This gives them escape velocities of 21 to 60 kilometers per second—much higher than the terrestrial planets. Consequently, it is more difficult for gases to escape from their gravitational pulls. Also, because the molecular motion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

Formation of the Solar System

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

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

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



Formation of the Solar System

Teacher Demo

Speeding Up a Spinning Nebula

L2

Purpose Students will see how rotational speed would have increased as the nebula contracted early in the formation of our solar system.

Materials a chair that can be spun in place

Procedure One person sits in the chair, and the chair is spun. The seated person extends his or her arms out to the sides, which will cause the spinning to slow. Then the seated person pulls his or her arms in, causing the spinning rate to increase. This activity can be repeated with multiple students.

Safety A lighter student will be easier to spin, however, you may prefer to be the person in the chair. The person in the chair should not move in any way other than to put his or her arms in and out.

Expected Outcomes Students will see that extended arms (representing the early, wider nebula) results in a slower spin. Pulling in the arms (representing the contracting nebula) causes an increase in spinning rate.
Visual, Kinesthetic

Answer to . . .

Figure 2 *The terrestrial planets are much smaller than the Jovian planets.*

Section 23.1 (continued)

3 ASSESS

Evaluate Understanding L2

Have students create quiz questions from this section and put them on flashcards. Then put the students in small groups where they will compete to see who can answer the most questions correctly. Put the cards in the center of the table, and have students take turns selecting a card and trying to answer it. If a student cannot answer the question on the card he or she selects, it is returned to the bottom of the pile. Students earn the card of each question they answer correctly. The winner is the one with the most cards at the end of the game.

Reteach L1

Have students summarize the differences between the terrestrial and Jovian planets by using the figures and tables in this section.

Math Practice

8. Show students how to use the equation: distance = rate / time to answer these questions. Since they are asked to find time, the equation can be rearranged as time = distance / rate.

Solutions

(1) 6.3×10^8 km ÷ 100 km/h = 6,300,000 h ÷ 24 h/day = 262,500 days ÷ 365 days/yr = 719 yrs
(2) 6.3×10^8 km ÷ 1000 km/h = 630,000 h ÷ 24 h/day = 26,250 days ÷ 365 days/yr = 72 yrs
(3) 6.3×10^8 km ÷ 40,000 km/h = 15,750 h ÷ 24 h/day = 656 days ÷ 365 days/yr = 1.8 yrs
(4) 6.3×10^8 km ÷ 300,000 km/s = 2100 s ÷ 60 s/ 1 min = 35 minutes

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

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

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

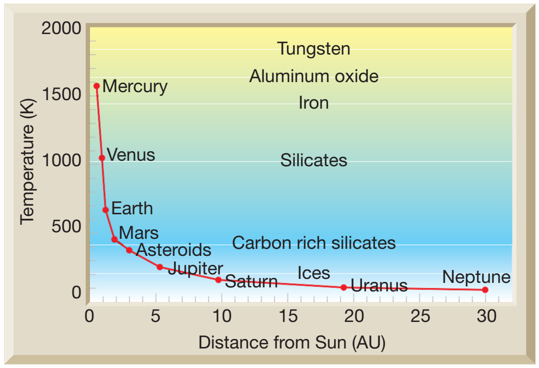


Figure 4 The terrestrial planets formed mainly from silicate minerals and metallic iron that have high melting points. The Jovian planets formed from large quantities of gases and ices.

Section 23.1 Assessment

Reviewing Concepts

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

Critical Thinking

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

Math Practice

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

Section 23.1 Assessment

1. Terrestrial: Mercury, Venus, Earth, and Mars; Jovian: Jupiter, Saturn, and Neptune
2. Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto
3. The terrestrial planets are small and rocky. The Jovian planets are gas giants.
4. A nebula is a cloud of dust and gas in space.
5. In the inner solar system, close to the sun, temperatures were so high that only metals and silicate minerals could form solid grains. Thus, the inner planets grew mainly from substances with high melting points. In the outer reaches of the solar system, it was cold enough for ices of water and other substances to form. Consequently, the Jovian planets grew not only from accumulations of solid bits of material but also from large quantities of gases and ices.
6. According to the nebular theory, the sun and planets formed from a rotating disk of dust and gases.
7. Sample answer: If Earth's orbit were outside the orbit of Mars, the extreme cold would freeze all water and only ice would exist. With only frozen water, there would be no precipitation, runoff, or infiltration—the water cycle and life itself would not exist.

23.2 The Terrestrial Planets

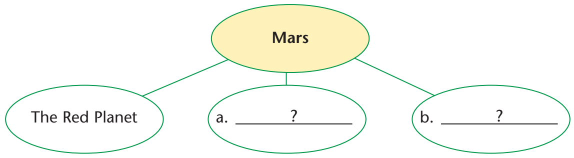
Reading Focus

Key Concepts

What are the distinguishing characteristics of each terrestrial planet?

Reading Strategy

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



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

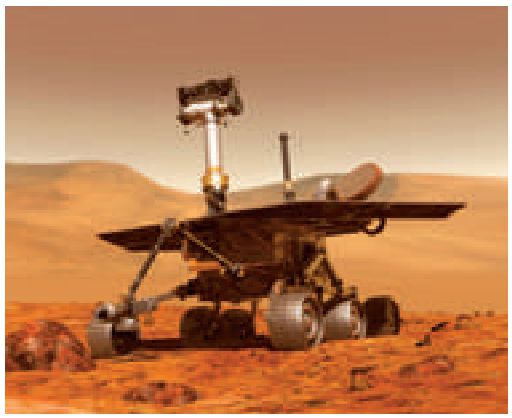


Figure 5 *Spirit* roved the surface of Mars and gathered data about the Red Planet's geologic past and present.

Mercury: The Innermost Planet

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

Section 23.2

1 FOCUS

Section Objective

23.3 **Describe** the distinguishing characteristics of each terrestrial planet.

Reading Focus

Build Vocabulary L2

Vocabulary List Encourage students to keep a list of new terms they encounter as they read this chapter. Have them use the context of each term to predict its definition. Go over the terms with the class. Some terms they may select are *rover, nonexistent, penetrate, veiled, summit, flank, advent,* and *prominent.*

Reading Strategy L2

Sample answers:
a. explored by rovers
b. numerous large volcanoes

Address Misconceptions L2

Some students may think that scientific knowledge is only acquired from controlled experiments. However, a great deal of scientific knowledge is a result of fieldwork and careful observations. In fact, a great deal of what we know about the universe and our solar system, we learned strictly from observation. To help students realize this, ask these questions as you teach this section. Ask: **What did we learn about Venus from the Magellan spacecraft?** *(Venus has varied topography like Earth.)* **What did we learn about Mars from the orbiting spacecraft Mariner 9?** *(Mars has volcanoes and canyons.)* **What did we learn about Mars from the rovers Spirit and Opportunity?** *(Mars has evaporite minerals and evidence of geological processes caused by liquid water; Mars has sand dunes and impact craters.)* **What did we learn from Mars Global Surveyor?** *(Underground springs may have existed on Mars.)* **Could we have learned these things simply from controlled experiments on Earth?** *(no)*
Verbal

2 INSTRUCT

Mercury: The Innermost Planet

Build Reading Literacy L1

Refer to **p. 362D** in **Chapter 13**, which provides guidelines for this reading strategy.

Use Prior Knowledge Have students make a web diagram for Mercury that includes information they already know about it. Have them add new information to their web as they read. Possible characteristics for web include: small, hot, closest to sun, has craters, very dense, revolves around sun quickly, rotates slowly, three months of night and three months of day, greatest temperature extremes of any planet.
Visual, Verbal

Venus: The Veiled Planet

Build Science Skills L2

Comparing and Contrasting Have students write a list of the similarities between Earth and Venus. *(size, density, mass, location in solar system, clouds, plateaus and mountains, volcanoes, have few impact craters)* Then have students create a chart contrasting Venus and Earth. For example:

Venus	Earth
One year is 255 Earth-days	One year is 365 Earth-days
Covered in thick clouds	Thin atmosphere
Very hot surface temperature	Surface temperature allows liquid water
97 percent of atmosphere is carbon dioxide	Very little of the atmosphere is carbon dioxide
Very little water vapor and nitrogen	Lots of water vapor and nitrogen
Atmospheric pressure is 90 times Earth's surface pressure	

Verbal, Visual

Go Online NSTA SCILINKS

Download a worksheet on extra-terrestrial volcanoes for students to complete, and find additional teacher support from NSTA SciLinks.

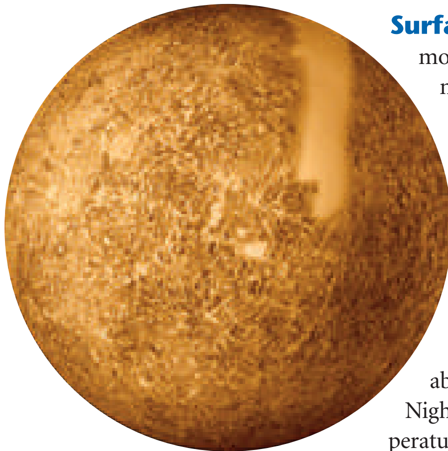


Figure 6 Mercury's surface looks somewhat similar to the far side of Earth's moon.

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

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

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

Venus: The Veiled Planet

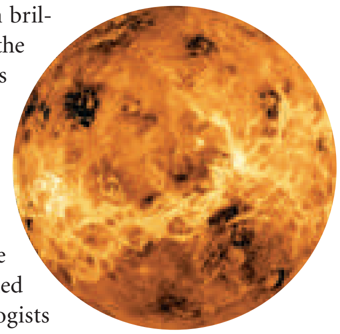


Figure 7 **Venus** This global view of the surface of Venus is computer generated from two years of Magellan Project radar mapping. The twisting bright features that cross the planet are highly fractured mountains and canyons of the eastern Aphrodite highland.

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

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

Go Online NSTA SCILINKS

For: Links on extraterrestrial volcanoes
Visit: www.SciLinks.org
Web Code: cjn-7232

Customize for English Language Learners

Have students use a thesaurus rather than a dictionary to look up unfamiliar words. This will help them learn the meaning of multiple words simultaneously. It is likely that at least one synonym listed is a word they know.

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

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

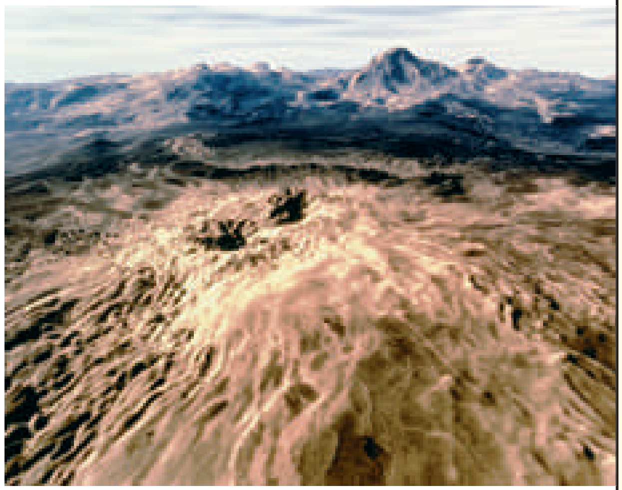


Figure 8 Sapas Mons and Maat Mons In this computer-generated image from Venus, Maat Mons, a large volcano, is near the horizon. Sapas Mons is the bright feature in the foreground.
Comparing and Contrasting ***What features on Venus are similar to those on Earth? What features are different?***

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

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

Mars: The Red Planet

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

Mars: The Red Planet

Use Community Resources L2

If possible, invite an astronomer or geologist in your community to talk to students about the findings of the rovers *Spirit* and *Opportunity* on Mars. Encourage students to list questions they have about Mars before the speaker comes to visit.
Verbal, Interpersonal

Integrate Chemistry L3

Polar Ice Caps Inform students that Mars has polar ice caps that are made mostly of frozen carbon dioxide, with some frozen water. Have advanced students brainstorm how these ice caps could be used to help make Mars habitable for humans.
Verbal, Logical

Facts and Figures

Mars has two natural satellites (moons), Phobos and Deimos. Although Mars is easy to observe from Earth, these moons were not discovered until 1977. Perhaps this is because they are only 24 and 15 km in diameter. Phobos is closer to Mars than any other natural satellite in the solar system, and it requires just 7 hours and 39 minutes for one revolution. *Mariner 9* found that both moons are irregularly shaped and have numerous impact craters.

Answer to . . .

Figure 8 *Features on Venus that are similar to those on Earth include plains, highlands, mountains, and volcanoes. Features on Venus that are different than those on Earth include thick clouds that can't be penetrated by visible light, volcanic flows covering most plains, thousands of volcanoes, no process of plate tectonics, and an atmosphere that can't sustain life.*

Reading Checkpoint *One full day-night cycle on Earth takes 24 hours. On Mercury, it requires 179 Earth-days.*

Reading Checkpoint *Venus's atmosphere is mainly made of carbon dioxide with traces of water vapor and nitrogen.*

Build Reading Literacy L1

Refer to **p. 1D** in **Chapter 1**, which provides guidelines for this reading strategy.

Anticipation Guide
Ask students to respond to the following questions in writing before they read the section on Mars. Have the students check over their answers and make changes as needed after they finish reading the section. Students should answer True or False to the following series of statements: **Mars's polar ice caps are mostly made of water.** *(False)* **There are active volcanoes on Mars.** *(False)* **Mars often has dust storms with hurricane force winds.** *(True)* **Mars has canyons that are much larger than Earth's Grand Canyon.** *(True)* **There is evidence that liquid water once flowed on Mars.** *(True)* **Liquid water currently flows on the Martian surface.** *(False)*
Verbal

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

The Martian Atmosphere

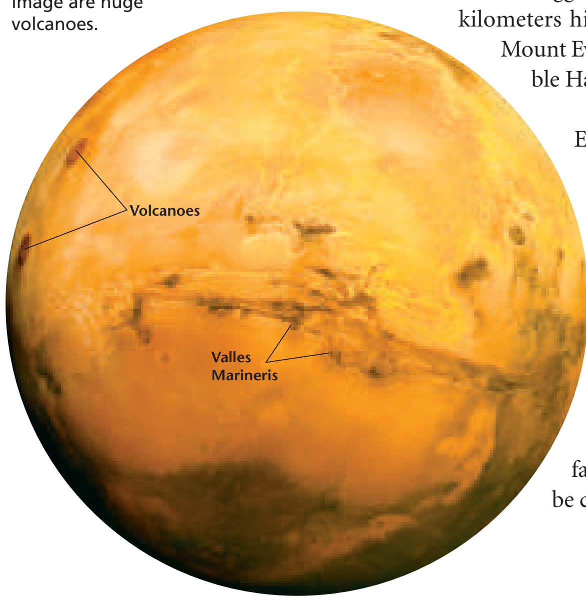
The Martian atmosphere has only 1 percent the density of Earth's. It is made up primarily of carbon dioxide with tiny amounts of water vapor. Data from Mars probes confirm that the polar caps of Mars are made of water ice, covered by a thin layer of frozen carbon dioxide. As winter nears in either hemisphere, temperatures drop to −125°C, and additional carbon dioxide is deposited. **Although the atmosphere of Mars is very thin, extensive dust storms occur and may cause the color changes observed from Earth. Hurricane-force winds up to 270 kilometers per hour can persist for weeks.** As shown in Figure 9, images from *Spirit* reveal a Martian landscape remarkably similar to a rocky desert on Earth, with abundant sand dunes and impact craters partially filled with dust.

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

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

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

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



Facts and Figures

Students may ask why the volcanoes on Earth are so much smaller than volcanoes on Mars. The reason is that Earth's crust is tectonically active, so the crust over a mantle plume is constantly moving. This motion creates a series of smaller volcanoes. Since Mars does not have plates that move, a volcano was able to grow larger and larger each time it erupted.

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

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

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

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

Section 23.2 Assessment

Reviewing Concepts

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

Critical Thinking

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

Writing in Science

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

3 ASSESS

Evaluate Understanding L2

Review with the class by stating a characteristic of one of the planets. Have students respond with the name of the planet having that characteristic.

Reteach L1

Have students make a colored sketch of each planet. They should list each planet's characteristics next to their sketch. Then have students put their sketches in order (Mercury out to Pluto) and display their work.

Writing in Science

Remind students that writing an editorial means stating a position and backing up that statement with factual evidence.

Student editorials should discuss both the costs and benefits of space exploration. Student opinions should be supported by facts.

Section 23.2 Assessment

1. Mercury
2. Venus is similar to Earth in size, density, mass, and location in the solar system.
3. Sample answer: Mercury has the greatest temperature extremes of any planet. Venus shows evidence of recent volcanic and tectonic activity. Earth is the only place where water exists in all three states. Mars experiences extensive dust storms and high winds.
4. volcanoes, sand dunes, and large canyons
5. Sample answer: Mars may have been the most able to support life because it may have had liquid water on its surface.
6. Venus's atmosphere is mainly made up of carbon dioxide, which traps radiation so the heat cannot escape.

Section 23.3

1 FOCUS

Section Objective

23.4 **Describe** the distinguishing characteristics of each Jovian planet.

Reading Focus

Build Vocabulary L2

Vocabulary Rating Chart Have students construct a chart with four columns labeled Word, Can Define or Use It, Heard or Seen It, and Don't Know. Have students copy words as they read the section into the first column and rate their word knowledge by putting a check in one of the other columns. Ask how many students actually know each word. Have them share their knowledge. Ask focused questions to help students predict text content based on the word, thus enabling them to have a purpose for reading. After students have read the section, have them rate their knowledge again.

Reading Strategy L2

Sample answers:
a. Saturn
b. largest ring system
c. Uranus
d. axis tilted more than 90°
e. Neptune
f. winds exceed 1000 km per hour
g. Pluto
h. orbit is highly eccentric

2 INSTRUCT

Jupiter: Giant Among Planets

Build Reading Literacy L1

Refer to **p. 392D** in **Chapter 14**, which provides guidelines for this reading strategy.

Preview Have students preview this section by skimming the headings and visuals. This will help students to activate their previous knowledge about the outer planets and will likely make them interested to read more about each planet.
Visual, Verbal

23.3 The Outer Planets

Reading Focus

Key Concepts

What characteristics distinguish each outer planet?

Reading Strategy

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

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

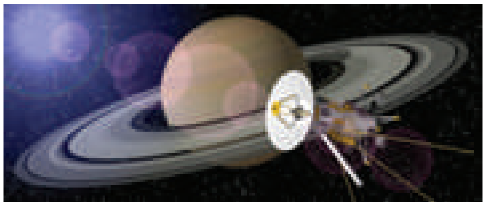


Figure 12 This artist's rendition shows *Cassini* approaching Saturn.

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

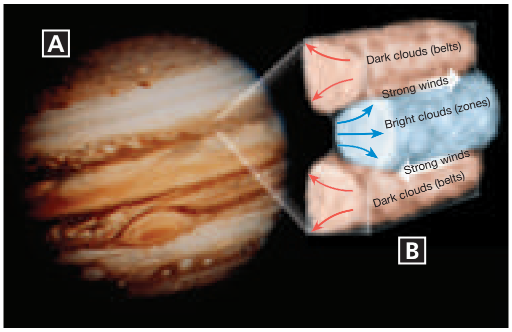


Figure 13 A When photographed by *Voyager 2,* the Great Red Spot was the size of two Earth-size circles placed side by side. **B** The light clouds are regions where gases are sinking and cooling. The convection currents and the rapid rotation of the planet generate high-speed winds.

Jupiter: Giant Among Planets

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

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

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

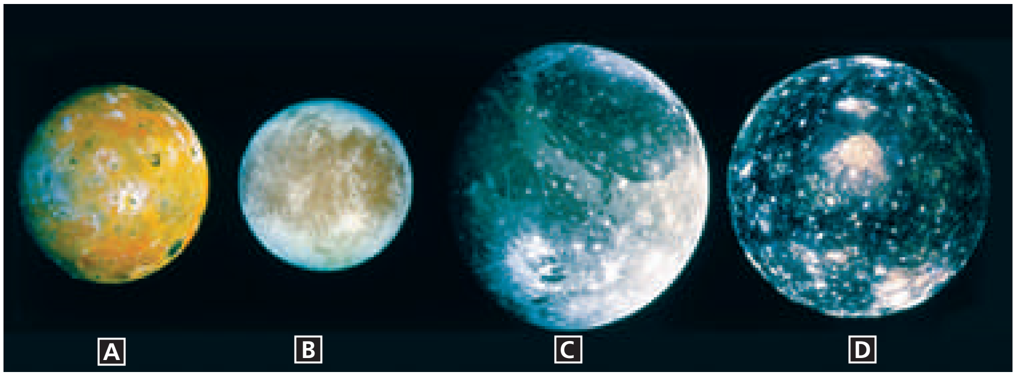
Atmospheric pressure at the top of the clouds is equal to sea-level pressure on Earth. Because of Jupiter's immense gravity, the pressure increases rapidly toward its surface. At 1000 kilometers below the clouds, the pressure is great enough to compress hydrogen gas into a liquid. Consequently, Jupiter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

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

Go Online SCI LINKS NSTA

For: Links on the outer planets
Visit: www.SciLinks.org
Web Code: cjn-7233

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



Use Visuals L1

Figure 14 This diagram shows Jupiter's four largest moons. Ask: **What do these moons have in common with each other?** *(They are all round, and they orbit around Jupiter.)* **Which of these moons have craters?** *(Europa, Callisto, and Io)* **Could Europa have craters?** *(Yes, but its surface is covered in ice.)* **Which of these moons has volcanoes?** *(Io)*
Visual

Integrate Language Arts L2

Mythological Characters All of the planets in our solar system, except for Earth, are named for characters or gods in Greek or Roman mythology. Have students work in groups. Each group should select the name of one planet to research. They should find out which mythological character or god the planet was named after, learn about the character, and determine why the name may have been given to the planet. For example, Mercury was named after the Roman messenger god because it is the planet with the fastest revolution rate around the sun. Each group should present their findings to the class.
Verbal, Interpersonal

Customize for English Language Learners

Have students create a concept map to organize what they will learn about the outer planets. Have them start with the main concept of the outer planets. Then have branches for Jupiter, Saturn, Uranus, Neptune, and Pluto, which they will expand on by filling in characteristics of each planet as they read.

Go Online NSTA SCI LINKS

Download a worksheet on the outer planets for students to complete, and find additional teacher support from NSTA SciLinks.

Saturn: The Elegant Planet

Build Reading Literacy L1

Refer to **p. 124D** in **Chapter 5**, which provides the guidelines for this Reading Strategy.

Summarize Have students summarize the major characteristics of Saturn as they read. For example, Saturn has wind, storms, many moons, and rings.
Verbal

Use Visuals L1

Figure 15 This diagram shows the rings of Saturn. Ask: **How are rings A and B different from ring C?** *(Ring C is a darker color.)* **What do you think is the cause of this difference?** *(They have different compositions.)* **How are the outer rings different from the inner rings?** *(The outer rings are much thinner than the inner rings.)* **How is ring E different from the other rings?** *(Ring E looks green, and is more diffuse.)*
Visual

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

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

Saturn: The Elegant Planet

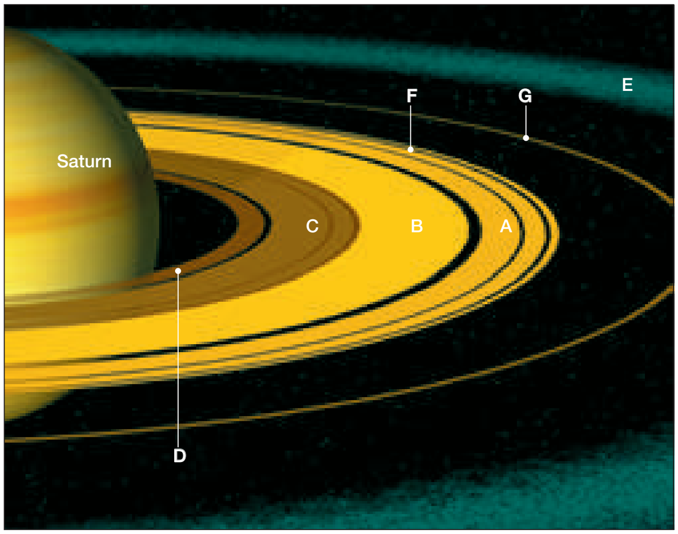


Figure 15 Saturn's Rings Saturn's rings fall into two categories based on particle density. The main rings (A and B) are densely packed. In contrast, the outer rings are composed of widely dispersed particles.

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

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

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

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

Facts and Figures

Scientists believe that liquid water is the key to the development of life, so they carefully search other planets and moons for this key ingredient. Studies of Jupiter's moon, Europa, have revealed that it is covered with a thick layer of ice, and scientists have inferred that there may be liquid water beneath this layer. This makes Europa a prime target for future space probes to look for evidence of life on this moon.

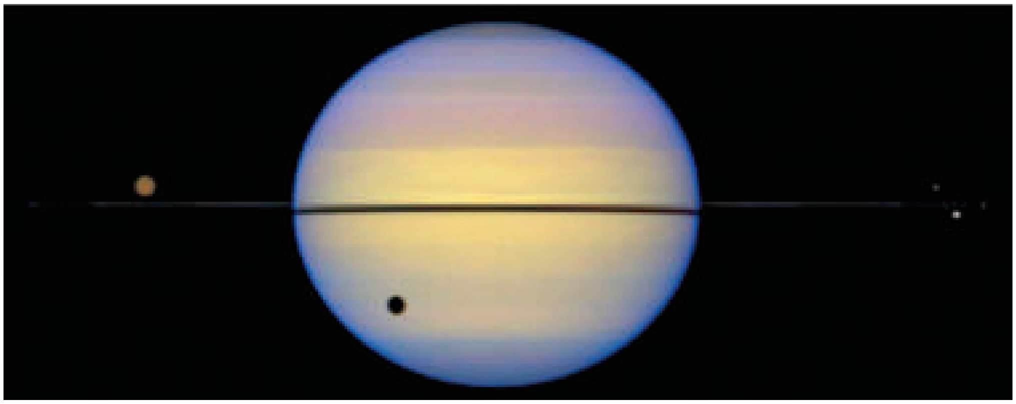


Figure 16 Saturn's Moons This image of Saturn shows several of its moons.

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

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

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

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

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

Build Science Skills

L2

Inferring After reading the section on Saturn's rings, have students take another look at the image of Saturn's rings in Figure 15. Ask students to use what they read and observed, in addition to their prior knowledge of how the solar system formed, to infer how Saturn's rings might have formed. Have students share their ideas with the class. Then share the information in the Facts and Figures box below with the class.
Visual, Logical

Facts and Figures

There are several theories regarding the origin of ring particles. Some scientists believe the rings formed out of a cloud of gas and dust from which the planet formed. Others believe the rings formed later when a moon or asteroid was pulled apart by the planet's gravity. Still others believe a crash with a foreign body blasted apart one of the planet's moon. Scientists hope that future missions to Saturn will help them resolve this controversy.

Answer to . . .

Reading Checkpoint *Io is volcanically active.*

Reading Checkpoint *Thirty-one moons have been discovered around Saturn.*

Uranus: The Sideways Planet

Teacher Demo

Discovering the Rings of Uranus

L2

Purpose Students will experience a simulation of how the rings of Uranus were discovered.

Materials meter stick, flashlight

Procedure Darken the classroom, and have one student hold the flashlight at the front of the room. Hold the meter stick horizontally to represent the rings of Uranus. While the student holds the flashlight steadily, pass the meter stick slowly up and down in front of the flashlight so it appears to blink on and off to the class. Explain to students that the flashlight represents the distant star which was blocked by Uranus in 1977. Help students understand that the rings would have caused the light of the star to blink on and off a few times as Uranus and its rings passed in front of the distant star.

Expected Outcome Students will see that Uranus's rings would have caused the occluded star to blink on and off a few times before and after the passing of Uranus's body in front of the star.
Visual, Kinesthetic

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

Uranus: The Sideways Planet

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

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

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

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

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

Neptune: The Windy Planet

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

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

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

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

Facts and Figures

The existence of Neptune was predicted before it was discovered. This prediction was based on irregularities in the orbit of Uranus and Newton's Universal Law of Gravitation. Scientists were ecstatic, in 1846, when Neptune was discovered exactly where it had been predicted. This discovery is an excellent example of a hypothesis being tested not in a lab, but in outer space itself.

Pluto: Planet X

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

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

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

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

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

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

Section 23.3 Assessment

Reviewing Concepts

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

Critical Thinking

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

Connecting Concepts

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

Pluto: Planet X

Build Science Skills L2

Comparing and Contrasting
Challenge students to find similarities and differences between Pluto and the other planets (both terrestrial and Jovian). They may also want to compare Pluto to some of the moons in our solar system.
Verbal

3 ASSESS

Evaluate Understanding L2

Put students in cooperative groups, and have them compare the summaries of this section that they made in response to this section's first Reading Strategy.

Reteach L1

Have students make concept maps for each outer planet that list its major characteristics.

Connecting Concepts

Before students begin writing, review with them how convection currents in Earth's atmosphere work. Describe their cause *(solar energy)*, what they look like *(hot, less dense air rises while cooler, denser air sinks)*, and some results of convection currents *(wind)*.

Sample answer: On Earth, atmospheric convection currents are driven by solar energy. Jupiter, however, gives off nearly twice as much heat as it receives from the sun. The interior heat from Jupiter produces huge convection currents in the atmosphere.

Section 23.3 Assessment

1. Jupiter is the largest planet. Pluto is the smallest.
2. a cyclonic storm
3. Sample answer: Jupiter is the largest planet. Saturn has an amazing ring system. Uranus's axis of rotation is nearly parallel with the plane of its orbit. Neptune is one of the windiest places in the solar system. Pluto is small and cold with a very eccentric orbit.
4. Titan and Triton are the only moons in the solar system with significant atmospheres.
5. Io is volcanically active, just like Earth. Neptune's moon Triton is also volcanically active.
6. A giant impact may have changed Uranus's spin.
7. Sample answer: Further study is likely required to determine if our definition of a planet still applies to Pluto.

Answer to . . .

Figure 18 *The Great Dark Spot is assumed to be a large rotating storm, much like Jupiter's Great Red Spot.*

Reading Checkpoint *Uranus's axis lies nearly parallel with the plane of its orbit.*

Section 23.4

1 FOCUS

Section Objectives

23.5 **Identify** the location within our solar system where most asteroids are found.

23.6 **Describe** the structure of a comet.

23.7 **Explain** the possible origins for a meteoroid.

Reading Focus

Build Vocabulary L2

Concept Map Have students make a concept map for the vocabulary terms in this section. The center of the map should be "Minor members of the solar system," the terms *asteroid*, *comet*, and *meteoroid* should branch off of this topic, and students should expand their map with the other vocabulary terms as they learn about each term.

Reading Strategy L2

a. small rocky body
b. comet
c. body made up of rocky and metallic materials held together by frozen gases
d. coma
e. glowing head of a comet
f. meteoroid
g. small solid particle that travels through space
h. meteor
i. meteoroid that enters Earth's atmosphere and burns up
j. meteorite
k. meteoroid that reaches Earth's surface

23.4 Minor Members of the Solar System

Reading Focus

Key Concepts

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

Vocabulary

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

Reading Strategy

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

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

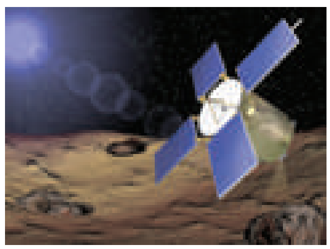


Figure 20 This artist's rendition shows *NEAR Shoemaker* touching down on the asteroid Eros.

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

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

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

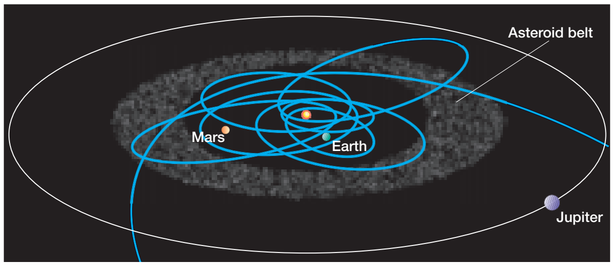


Figure 21 The orbits of most asteroids lie between Mars and Jupiter. Also shown are the orbits of a few near-Earth asteroids. Perhaps a thousand or more asteroids pass close to Earth. Luckily, only a few dozen are thought to be larger than 1 kilometer in diameter.

Asteroids: Microplanets

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

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

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

Reading Checkpoint *What is an asteroid?*

Comets

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

2 INSTRUCT

Asteroids: Microplanets

Use Visuals L1

Figure 21 This image shows the orbital paths of several asteroids in our solar system. Have students look carefully at the figure and read the caption. Ask: **Where are most asteroids found?** *(between Mars and Jupiter, in the asteroid belt)* **Are most of the asteroids near Earth found in the asteroid belt?** *(no)* **What is the shape of all of the asteroid orbits?** *(elliptical)*
Visual

Comets

Build Reading Literacy L1

Refer to **p. 306D** in **Chapter 11**, which provides guidelines for this reading strategy.

KWL Create a KWL chart with students before reading the section on comets. Students will probably already know that comets are "dirty snowballs," and will be able to name at least one comet. What students want to know will vary. After teaching the section on comets, have students complete the chart on what they learned. Clarify learning as needed.
Verbal

Customize for English Language Learners

Put beginning English language learners in groups with native English speakers of average to below-average ability. These groups will allow the conversations to be at appropriate levels. Have students work together over a few class periods to complete their concept maps for this section's vocabulary words. Once ELL students reach the intermediate level, they can work with average to above-average students.

Answer to . . .

Reading Checkpoint *An asteroid is a small, irregularly shaped body in space.*

Teacher Demo

Modeling a Comet's Tail L2

Purpose The demonstration will help students understand why a comet's tail always points away from the sun.

Materials tabletop fan, light-weight paper, tape

Procedure Have students create simple models of comets using a ball of paper or an actual ball as the coma with light-weight paper streamers as the tail. Turn on the fan, and have students hold their models in the breeze. The streamers will always point away from the fan's breeze.

Expected Outcome Students will see how radiation pressure and solar wind will cause a comet's tail to always point away from the sun.
Visual, Kinesthetic

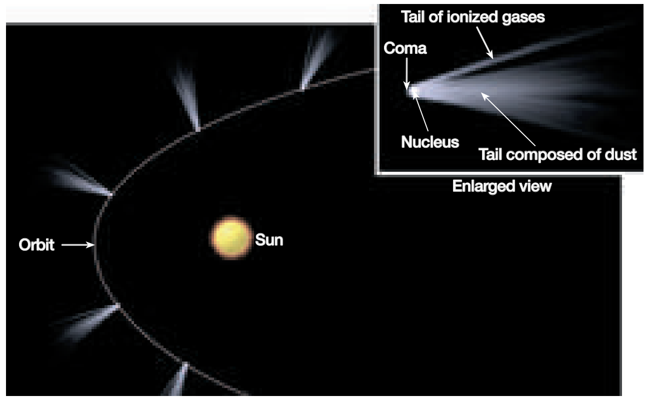


Figure 23 A comet's tail always points away from the sun.

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

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

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

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

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

Facts and Figures

Many of the scientists who want to declassify Pluto as a planet consider it a Kuiper belt object. The highly eccentric orbit of Pluto, its size, and its icy and rocky composition, give it the characteristics of many other objects orbiting the sun in the Kuiper belt.

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

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

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

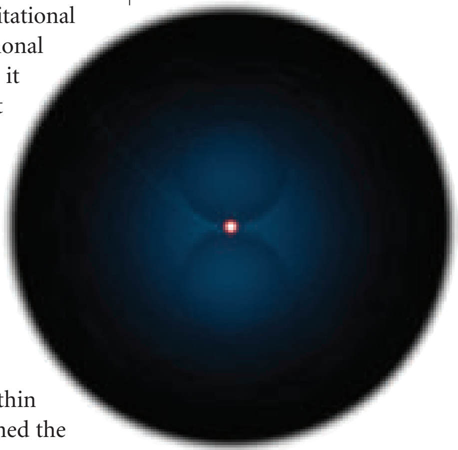


Figure 24 The Oort cloud is a sphere of comets surrounding the sun and planets.

Meteoroids

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

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

Meteoroids

Build Reading Literacy L1

Refer to **p. 612D** in **Chapter 22**, which provides the guidelines for this reading strategy.

Think Aloud The first paragraph of the Meteoroids section is very important, but it contains many words that may confuse students. Read this paragraph out loud, and stop at the end of each sentence to ask yourself (and the class) a question to check for comprehension. For example, after the first sentence you can ask, "Have I ever seen a shooting star?" The third sentence is completely in bold, meaning it is really important so you may want to ask multiple questions about that one, such as "What is interplanetary debris? Where's the asteroid belt? What would the remains of a comet look like?" If your students are not able to answer your questions, encourage them to go back in the chapter to find the answers. For example, students may need to reread the section on comets to figure out what the remains of a comet are.
Verbal, Intrapersonal

Facts and Figures

Scientists have hypothesized that comets may contain organic material, and the Giotto probe observed what appeared to be organic material on the surface of Halley's comet. Since comets occasionally come close the Earth, or even crash into Earth's surface, some people believe that life on Earth originated from organic material carried to our planet by a comet.

Answer to . . .

Reading Checkpoint: *away from the sun*

Build Reading Literacy L1

Refer to **p. 474D** in **Chapter 17**, which provides the guidelines for this reading strategy.

Monitor Your Understanding
After students have read the paragraphs on meteoroids, advise students to make sure they understand the difference between meteoroids, meteors, and meteorites. Also, have them verify that they recognize the relationship between meteor showers and comets. Recommend to students that they reread the passage if they did not understand these ideas.
Verbal, Intrapersonal

3 ASSESS

Evaluate Understanding L2

Check for understanding by putting the students in groups and having the groups write an answer for each Key Concept question in the chapter.

Reteach L1

Review the content in this chapter with a series of Venn diagrams or concept maps.

Math Practice

Solution
7. 1×10^{11} tons of mass $\div$ 1×10^{8} tons of mass lost/orbit $= 1 \times 10^{3}$ or 1000 orbits remaining; 76 years/orbital period $\times$ 1,000 orbits $=$ 76,000 years of life remaining

Table 2 Major Meteor Showers

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

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

Reading Checkpoint ***What is a meteor shower?***

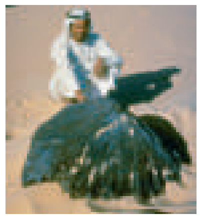


Figure 25 This meteorite, made up of mostly iron, was found in the desert sands.

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

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

Section 23.4 Assessment

Reviewing Concepts

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

Critical Thinking

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

Math Practice

7. It has been estimated that Halley's comet has a mass of 1 x 10^{11} tons. This comet is estimated to lose 1 x10^{8} tons of material each time its orbit brings it close to the sun. With an orbital period of 76 years, what is the maximum remaining life span of Halley's comet?

Section 23.4 Assessment

1. Most asteroids lie between the orbits of Mars and Jupiter.
2. A comet is made up of frozen gases and pieces of rocky and metallic materials. As the comet approaches the sun, vaporizing gases produce a glowing head called a coma. Within the coma, a small glowing nucleus is sometimes present. Most comets have long tails.
3. Short-period comets come from the Kuiper belt. Long-period comets come from the Oort cloud.
4. Most meteoroids originate from: (1) interplanetary debris that was not gravitationally swept up by the planets during the formation of the solar system, (2) material form the asteroid belt, or (3) the solid remains of comets that once traveled near Earth's orbit.
5. Meteoroids are small solid particles traveling through space. Meteors are meteoroids that enter Earth's atmosphere and burn up. Meteorites are meteoroids that strike Earth's surface.
6. Sample answer: There would be a huge meteor shower.

earth as a SYSTEM

Is Earth on a Collision Course?

The solar system is cluttered with meteoroids, asteroids, active comets, and extinct comets. These fragments travel at great speeds and can strike Earth with the explosive force of a powerful nuclear weapon.

Ancient Collisions

During the last few decades, it has become increasingly clear that comets and asteroids have collided with Earth far more frequently than was previously known. The evidence for these collisions is giant impact structures. See Figure 26. More than 100 impact structures have been identified as shown on the map in Figure 27. Most are so old that they no longer resemble impact craters. However, evidence of their intense impact remains. One notable exception is a very fresh-looking crater near Winslow, Arizona, known as Meteor Crater.

Evidence is mounting that about 65 million years ago a large asteroid about 10 kilometers in diameter collided with Earth. This impact may have caused the extinction of the dinosaurs, as well as nearly 50 percent of all plant and animal species.

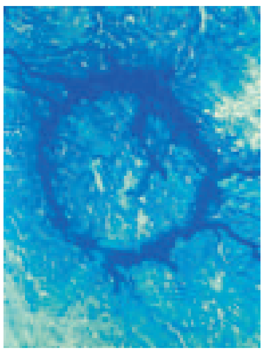


Figure 26 Manicouagan, Quebec, is a 200-million-year-old eroded impact structure. The lake outlines the crater remnant.

Close Calls

More recently, a spectacular explosion has been linked to the collision of our planet with a comet or asteroid. In 1908, in a remote region of Siberia, a "fireball" that appeared more brilliant than the sun exploded with a violent force. The shock waves rattled windows and triggered reverberations heard up to 1000 kilometers away. The "Tunguska event," as it is called, scorched, de-limbed, and flattened trees up to 30 kilometers from the epicenter. However, expeditions to the area did not find any evidence of an impact crater or metallic fragments. It is believed that the explosion—which equaled at least a 10-megaton nuclear bomb—occurred a few kilometers above the surface. It was most likely the end of a comet or perhaps a stony asteroid. The reason it exploded prior to impact remains unclear.

A reminder of the dangers of living with these small but deadly objects from space came in 1989 when an asteroid—nearly 1 kilometer across—shot past Earth. The asteroid came close to Earth, passing it by only twice the distance to the moon. It traveled at a speed of 70,000 kilometers per hour, and it could have made an impact crater 10 kilometers in diameter and perhaps 2 kilometers deep.

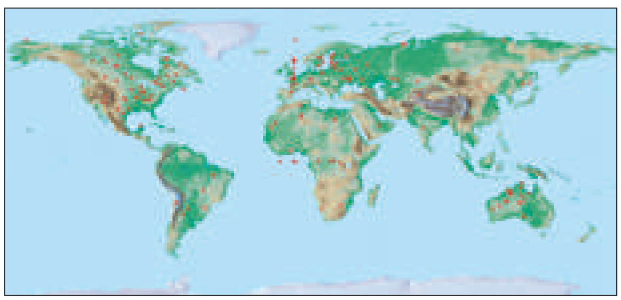


Figure 27 World Map of Major Impact Structures

earth as a SYSTEM

Is Earth on a Collision Course? L2

Background
The solar system is cluttered with meteoroids, asteroids, active comets, and extinct comets. These fragments travel at great speeds and can strike Earth with the explosive force of a powerful nuclear weapon.

Teaching Tip
Tell students to imagine they were close enough to the Tunguska event to see it. Have them write what they experienced—saw, heard, or smelled—during the event, how they felt, and what they thought it was. This can be written in the format of a newspaper article or diary entry.
Verbal

Answer to . . .

Reading Checkpoint *a display of numerous meteors burning up in Earth's atmosphere*

Section 24.1

1 FOCUS

Section Objectives

24.1 **Describe** the waves that compose the electromagnetic spectrum.

24.2 **Describe** what the different types of spectra reveal about stars.

24.3 **Explain** how the Doppler effect is applied to the motion of stars in relation to Earth.

Reading Focus

Build Vocabulary L2

Vocabulary Rating Chart Have students make a chart with four columns with the headings Term, Can Define or Use It, Heard or Seen It, and Don't Know. Have students copy the seven vocabulary terms into the first column and rate their knowledge by putting a checkmark in one of the other columns. Ask how many students actually know each term. Then, give students a purpose for reading by asking focused questions to help students predict text content based on each term. After students have read the section, have them rate themselves again.

Reading Strategy L2

a. Answers will vary.
b. The electromagnetic spectrum is the arrangement of electromagnetic radiation including gamma rays, X-rays, ultraviolet light, visible light, infrared radiation, microwaves, and radio waves according to their wavelengths and frequencies.

24.1 The Study of Light

Reading Focus

Key Concepts

- What types of radiation make up the electromagnetic spectrum?
- What can scientists learn about a star by studying its spectrum?
- How can astronomers determine whether a star is moving toward or away from Earth?

Vocabulary

- electromagnetic spectrum
- photon
- spectroscopy
- continuous spectrum
- absorption spectrum
- emission spectrum
- Doppler effect

Reading Strategy

Predicting Copy the table. Before you read, predict the meaning of the term *electromagnetic spectrum.* After you read, revise your definition if it was incorrect.

Vocabulary Term	Before You Read	After You Read
electromagnetic spectrum	a. ___?___	b. ___?___

Astronomers are in the business of gathering and studying light. Almost everything that is known about the universe beyond Earth comes by analyzing light from distant sources. Consequently, an understanding of the nature of light is basic to modern astronomy. This chapter deals with the study of light and the tools used by astronomers to gather light in order to probe the universe. In addition, we will examine the nearest source of light, our sun. By understanding how the sun works, astronomers can better grasp the nature of more distant objects in space.

Electromagnetic Radiation

The vast majority of our information about the universe is obtained from the study of the light emitted from stars and other bodies in space. Although visible light is most familiar to us, it makes up only a small part of the different types of energy known as electromagnetic radiation. **Electromagnetic radiation includes gamma rays, X-rays, ultraviolet light, visible light, infrared radiation, microwaves, and radio waves.** The arrangement of these waves according to their wavelengths and frequencies is called the **electromagnetic spectrum.** Figure 1 shows the electromagnetic spectrum. All energy, regardless of wavelength, travels through the vacuum of space at the speed of light, or 300,000 kilometers per second. Over a 24-hour day, this equals a staggering 26 billion kilometers.

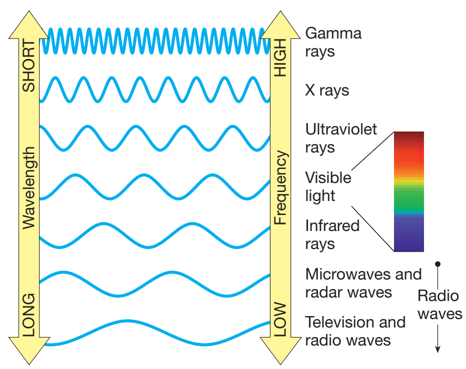


Figure 1 Electromagnetic Spectrum The electromagnetic spectrum classifies radiation according to wavelength and frequency.
Interpreting Diagrams ***Which type of radiation has the shortest wavelength?***

Nature of Light Experiments have shown that light can be described in two ways. In some instances light behaves like waves, and in others like particles. In the wave sense, light can be thought of as swells in the ocean. This motion is characterized by a property known as wavelength, which is the distance from one wave crest to the next. Wavelengths vary from several kilometers for radio waves to less than a billionth of a centimeter for gamma rays, as shown in Figure 1. Most of these waves are either too long or too short for our eyes to see.

The narrow band of electromagnetic radiation we can see is sometimes called visible light. However, visible light consists of a range of waves with various wavelengths. This fact is easily demonstrated with a prism, as shown in Figure 2. As visible light passes through a prism, the color with the shortest wavelength, violet, is bent more than blue, which is bent more than green, and so forth. Thus, visible light can be separated into its component colors in the order of their wavelengths, producing the familiar rainbow of colors.

Table 1 Colors and Corresponding Wavelengths

Color	Wavelength (nanometers*)
Violet	380–440
Blue	440–500
Green	500–560
Yellow	560–590
Orange	590–640
Red	640–750

One nanometer is 10^{-9} meter.

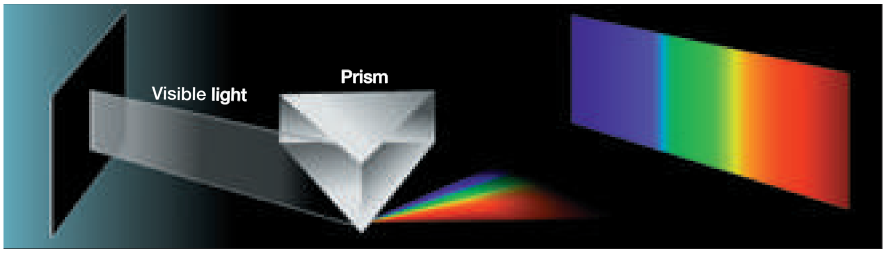


Figure 2 Spectrum A spectrum is produced when sunlight or visible light is passed through a prism, which bends each wavelength at different angles.

Photons Wave theory, however, cannot explain some effects of light. In some cases, light acts like a stream of particles called **photons.** Photons can be thought of as extremely small bullets fired from a machine gun. They can push on matter. The force they exert is called radiation pressure. Photons from the sun are responsible for pushing material away from a comet to produce its tail. Each photon has a specific amount of energy, which is related to its wavelength in a simple way: Shorter wavelengths have more energetic photons. Thus, blue light has more energetic photons than does red light.

Which theory of light—the wave theory or the particle theory—is correct? Both, because each will predict the behavior of light for certain phenomena. As George Abell, a well-known astronomer, stated about all scientific laws, "The mistake is only to apply them to situations that are outside their range of validity."

Reading Checkpoint *What are photons?*

Go Online SCILINKS NSTA

For: Links on the electromagnetic spectrum
Visit: www.SciLinks.org
Web Code: cjn-7441

Customize for English Language Learners

The details of electromagnetic radiation, spectroscopy, and the Doppler effect may be difficult for students that are learning English. Simplify your presentation so they will have better comprehension of the material. Speak clearly, use simple words and short sentences, and make frequent use of diagrams to clarify the material in this section.

2 INSTRUCT

Electromagnetic Radiation

Use Visuals L1

Figure 1 Point out to students that although these waves have different frequencies and wavelengths, they travel at the same speed in a vacuum, which is 3.00×10^8 m/s. Ask: **What is the product of any electromagnetic frequency and its wavelength?** *(the speed of light, 3.00×10^8 m/s)* **What happens to the wavelength of an electromagnetic wave as the frequency decreases?** *(The wavelength increases.)*
Verbal, Logical

Build Science Skills L2

Calculating Have students use the data in Table 1 to find the frequencies of violet and red light. Tell students to use the lower value for the wavelength in their calculations. *(violet: 7.9×10^{14} 1/s or Hz; red: 4.7×10^{14} Hz)* Ask: **Which color has the longer wavelength?** *(red)* **Which color has the highest frequency?** *(violet)*
Visual, Logical

Build Reading Literacy L1

Refer to **p. 672D**, which provides the guidelines for summarizing.

Summarize Summarizing the information presented in the text will help students focus on main ideas and remember what they read. Have students read the paragraphs about electromagnetic radiation and summarize them by restating the main idea in their own words.
Verbal

Go Online NSTA SCILINKS

Download a worksheet on the electromagnetic spectrum for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 1 *gamma rays*

Reading Checkpoint *Photons are streams of particles of light that exert radiation pressure.*

Spectroscopy

Teacher Demo

Making a Simple Spectrometer

L2

Purpose Students will observe how a spectrometer breaks light into the wavelengths that compose it.

Materials empty paper towel cardboard tube, diffracting grating (about 5 cm × 5 cm), piece of black paper (about 9 cm × 9 cm), tape, rubber band, razor blade, bright light

Procedure Tape the diffracting grating over one end of the cardboard tube. Cover the opposite end of the tube with black paper. Secure the black paper over the end of the tube with a rubber band. Carefully cut a narrow slit in the center of the black paper. The slit should be about two-thirds the width of the opening. Point the slit toward a bright light and slowly rotate the tube until you see the spectrum. Allow students to use the spectrometer to view the spectrum.

Safety Do not allow students to use this spectrometer to directly view the sun.

Expected Outcome The diffraction grating works like a prism and breaks visible light into its basic colors. Students will be able to use this simple spectrometer to see bright light broken into its component colors or wavelengths.
Visual, Kinesthetic

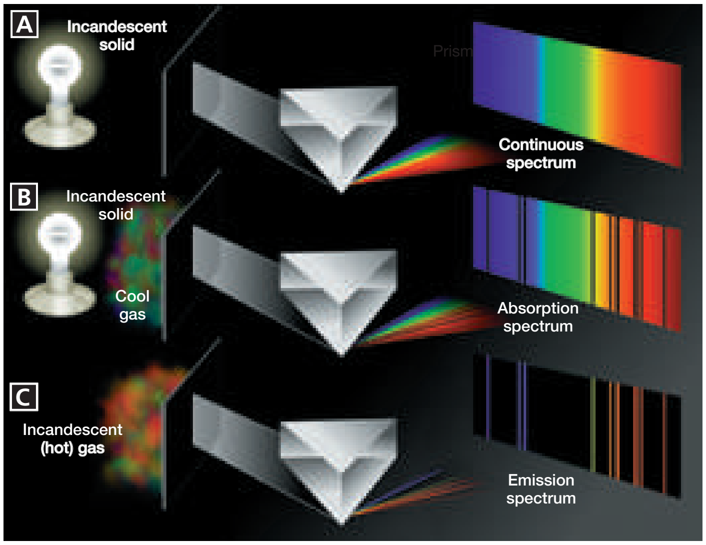


Figure 3 Formation of Spectra
A A continuous spectrum consists of a band of uninterrupted color. **B** An absorption spectrum contains dark lines. **C** An emission spectrum contains bright lines.

Spectroscopy

When Sir Isaac Newton used a prism to disperse visible light into its component colors, he unknowingly introduced the field of spectroscopy. **Spectroscopy** is the study of the properties of light that depend on wavelength. The rainbow of colors Newton produced included all wavelengths of light. It was later learned that two other types of spectra exist. Each is generated under somewhat different conditions.

Continuous Spectrum A **continuous spectrum** is produced by an incandescent solid, liquid, or gas under high pressure. (*Incandescent* means "to emit light when hot.") The spectrum consists of an uninterrupted band of color, as shown in Figure 3A. One example would be light generated by a common light bulb. This is the type of spectrum Newton produced.

Absorption Spectrum An **absorption spectrum** is produced when visible light is passed through a relatively cool gas under low pressure. The gas absorbs selected wavelengths of light. So the spectrum appears continuous, but with a series of dark lines running through it, as shown in Figure 3B.

Emission Spectrum An **emission spectrum** is produced by a hot gas under low pressure. It is a series of bright lines of particular wavelengths, depending on the gas that produces them. As shown in Figure 3C, these bright lines appear in the exact location as the dark lines that are produced by the same gas in an absorption spectrum.

The spectra of most stars are of the dark-line, or absorption, type. The importance of these spectra is that each element or compound in its gaseous form produces a unique set of spectral lines. **When the spectrum of a star is studied, the spectral lines act as "fingerprints." These lines identify the elements present and thus the star's chemical composition.** The spectrum of the sun contains thousands of dark lines. More than 60 elements have been identified by matching these lines with those of elements known on Earth.

Reading Checkpoint *What is spectroscopy?*

The Doppler Effect

When an ambulance approaches, the siren seems to have a higher-than-normal pitch. When it is moving away, the pitch sounds lower than normal. This effect, which occurs for both sound and light waves, is called the Doppler effect. The **Doppler effect** refers to the perceived change in wavelength of a wave that is emitted from a source that is moving away or toward an object. It takes time for the wave to be emitted. If the source is moving away from you, the beginning of the wave is emitted nearer to you than the end. From the listener's perspective the wave appears to be stretched, as shown in the model for Figure 4. The opposite is true for a wave moving toward you.

The light from a source that is moving away from an observer appears redder than it actually is because its waves are lengthened. This effect is only noticeable to the human eye at velocities approaching the speed of light. Objects moving toward an object have their light waves shifted toward the blue, or shorter wavelength. In addition, the amount of shift is related to the rate of movement. Thus, if a source of red light moved toward you, it could actually appear blue. The same effect would be produced if you moved and the light source was stationary.

In astronomy, the Doppler effect is used to determine whether a star or other body in space is moving away from or toward Earth. Larger Doppler shifts indicate higher speeds; smaller Doppler shifts indicate slower speeds. Doppler shifts are generally measured from the dark lines in the spectra of stars by comparing them with a standard spectrum produced in the laboratory.

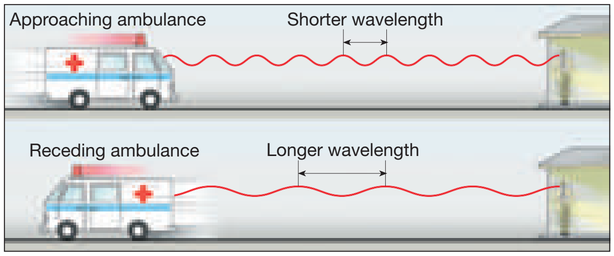


Figure 4 The Doppler Effect The wavelength of the sound of an approaching ambulance is compressed as it approaches an observer. For a receding ambulance, the wavelength is stretched out and the observer notes a lower-pitched sound. When this effect is applied to light, a shorter wavelength is noted for an approaching object and is seen as blue light. A longer wavelength is noted for a receding object, which is seen as red light.

Section 24.1 Assessment

Reviewing Concepts

1. What types of radiation make up the electromagnetic spectrum?
2. Compare and contrast the three different types of spectra.
3. How do scientists determine the elements present in a star?
4. How can scientists determine whether a star is moving toward or away from Earth?

Critical Thinking

5. **Sequencing** Sequence the components of visible light according to wavelength, beginning with the shortest wavelength.
6. **Applying Concepts** Based on what you know about visible light, how do rainbows form in Earth's atmosphere?

Writing in Science

List of Questions Make a list of questions that you would like to ask a scientist about the nature of light. Your questions should cover both the wave theory and the particle theory of light.

The Doppler Effect

Integrate Physics L2

A Sonic Boom The Doppler effect and a sonic boom are similar phenomena. When an object such as an airplane is traveling near the speed of sound, the compression waves bunch up near the nose of the aircraft. When the aircraft exceeds the speed of sound, a loud explosion is heard known as a sonic boom. The sonic boom occurs because some of the sound wavefronts arrive at the same instant. Have students research how a sonic boom and a Mach cone are created. Have students make posters showing how each of these phenomena occurs.
Verbal

3 ASSESS

Evaluate Understanding L2

Have students write one question on each of the following topics: electromagnetic radiation, spectroscopy, and the Doppler effect. Have groups of students ask one another their questions.

Reteach L1

Use Figure 3 on p. 676 to review the different types of spectrums.

Writing in Science

Sample questions: In which circumstances does light behave like a wave? When does it behave like a stream of particles? Who developed the theories? If time permits, have students research the answers to their questions.

Answer to . . .

Reading Checkpoint *Spectroscopy is the study of the properties of light that depend on wavelength.*

Section 24.1 Assessment

1. Electromagnetic radiation includes gamma rays, X-rays, ultraviolet light, visible light, infrared radiation, microwaves, and radio waves.
2. A continuous spectrum is produced by an incandescent solid, liquid, or gas under high pressure. It consists of an uninterrupted band of color. An absorption spectrum is produced when white light is passed through a relatively cool gas under low pressure. The spectrum appears continuous, but with a series of dark lines running through it. An emission spectrum is produced by a hot gas under low pressure. It is a series of bright lines of particular wavelengths, depending on the gas that produces them.
3. Scientists study the star's spectrum. The spectral lines act as "fingerprints," which identify the elements present and thus the star's chemical composition.
4. Scientists study Doppler shifts. A red shift indicates that a star is moving away from Earth. A blue shift indicates that a star is moving toward Earth.
5. violet, blue, green, yellow, orange, and red
6. Visible light is bent when it encounters water droplets in the atmosphere and is separated into its component colors.

Section 24.2

1 FOCUS

Section Objectives

24.4 **Explain** how refracting, reflecting, and radio telescopes work.

24.5 **Describe** the advantages and disadvantages of each type of telescope.

24.6 **Explain** the advantages that a space telescope has over an Earth-based telescope.

Reading Focus

Build Vocabulary L2

Concept Map Have students make a concept map using the term *telescopes* as the starting point. All the vocabulary terms in this section should be used.

Reading Strategy L2

a. uses a lens to bend and redirect light to a focal point behind a mirror
b. uses a concave mirror to focus light to a point in front of a mirror

2 INSTRUCT

Refracting Telescopes

Build Reading Literacy L1

Refer to **p. 642D** in **Chapter 23**, which provides the guidelines for comparing and contrasting.

Compare and Contrast Have students read the section. As they read, they should create lists of how the various types of telescopes are similar and different.
Verbal

24.2 Tools for Studying Space

Reading Focus

Key Concepts

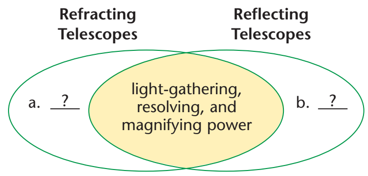
- How does a refracting telescope produce an image?
- Why are most large telescopes reflecting telescopes?
- How does a radio telescope gather data?
- What advantages do space telescopes have over Earth-based telescopes?

Vocabulary

- refracting telescope
- chromatic aberration
- reflecting telescope
- radio telescope

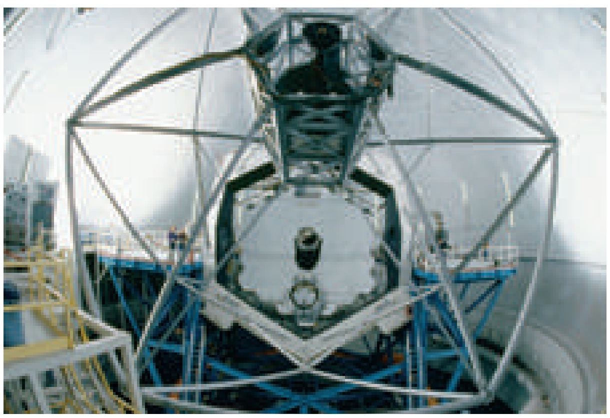
Reading Strategy

Comparing and Contrasting Copy the Venn diagram. As you read, complete it to show the differences between refracting and reflecting telescopes.



Now that we've examined the nature of light, let's turn our attention to the tools astronomers use to intercept and study the energy emitted by distant objects in the universe. Because the basic principles of detecting radiation were originally developed through visual observations, the astronomical tools we'll explore first will be optical telescopes. An example is shown in Figure 5. The 10-meter Keck Telescope, located on Mauna Kea in Hawaii, uses a mosaic of 36 six-sided, 1.8-meter mirrors. The mirrors are carefully positioned by a computer to give the optical effect of a 10-meter mirror. The Keck Telescope is a type of optical telescope. To create an image that is a great distance away, a telescope must collect as much light as possible. Optical telescopes contain mirrors, lenses, or both to accomplish this task.

Figure 5 Keck Telescope This optical telescope is located at the summit of Hawaii's Mauna Kea volcano.



Refracting Telescopes

Galileo is considered to be the first person to have used telescopes for astronomical observations. Having learned about the newly invented instrument, Galileo built one of his own that was capable of magnifying objects 30 times. Because this early instrument, as well as its modern counterparts, used a lens to bend or refract light, it is known as a **refracting telescope.**

Focus The most important lens in a refracting telescope, the objective lens, produces an image by bending light from a distant object so that the light converges at an area called the focus (*focus* = central point). For an object such as a star, the image appears as a point of light. For nearby objects it appears as an inverted replica of the original.

You can easily demonstrate the latter case by holding a lens in one hand and, with the other hand, placing a white card behind the lens. Now vary the distance between them until an image appears on the card. The distance between the focus (where the image appears) and the lens is called the focal length of the lens.

Astronomers usually study an image from a telescope by first photographing the image. However, if a telescope is used to examine an image directly, a second lens, called an eyepiece, is required. The eyepiece magnifies the image produced by the objective lens. In this respect, it is similar to a magnifying glass. The objective lens produces a very small, bright image of an object, and the eyepiece enlarges the image so that details can be seen. Figure 6 shows the parts of a refracting telescope.

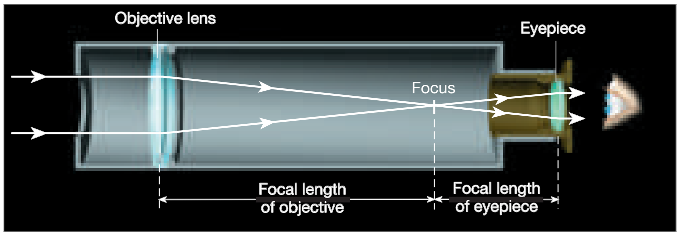


Figure 6 Simple Refracting Telescope A refracting telescope uses a lens to bend light.

Chromatic Aberration Although used extensively in the nineteenth century, refracting telescopes suffer a major optical defect. As light passes through any lens, the shorter wavelengths of light are bent more than the longer wavelengths. Consequently, when a refracting telescope is in focus for red light, blue and violet light are out of focus. The troublesome effect, known as **chromatic** (*chroma* = color) **aberration** (*aberrare* = to go astray), weakens the image and produces a halo of color around it. When blue light is in focus, a reddish halo appears. When red light is in focus, a bluish halo appears. Although this effect cannot be eliminated completely, it is reduced by using a second lens made of a different type of glass.

Reading Checkpoint *What is chromatic aberration?*

Use Community Resources L2

Invite an astronomer to talk to your class about telescopes. Ask if he or she could bring small telescopes to use for demonstrations. If possible, see if the astronomer could come at night and have a moon-gazing or star-gazing party.
Verbal, Interpersonal

Teacher Demo

Making a Simple Refracting Telescope L2

Purpose Students will observe the simple concepts behind a refracting telescope.

Materials 2 magnifying lenses

Procedure Observe an object in the distance with one of the magnifying lenses. Move the lens back and forth until you get a sharp image. Place the second magnifying lens in front of your eye. Move the second lens back and forth until you get a clear image. The image should appear larger. Pass the lenses around the classroom to give students an opportunity to view an image.

Expected Outcome Students will see that a simple refracting telescope consists of two lenses. In this example, it consists of two convex lenses. A convex lens is thicker in the middle and thinner around the edges.
Visual, Kinesthetic

Customize for Inclusion Students

Learning Disabled For students with difficulty absorbing concepts by reading, use Figures 6, 7, and 8 as a visual aid as you describe how each of these telescopes work. Be sure students understand the differences in these telescopes.

Answer to . . .

Reading Checkpoint *Chromatic aberration is a troublesome effect associated with refracting telescopes that weakens an image and produces a halo of color around it.*

Reflecting Telescopes

Use Visuals L1

Figure 7 Have students examine the figure. Ask: **Where is the viewer positioned for each type of reflecting telescope?** *(In A, the viewer is in a viewing cage inside the telescope, positioned at the focal point. In B, the viewer is seated below the telescope at the focal point. In C, the viewer is at the side of the telescope, viewing the image at an angle.)* **Infer why the prime focus method is used only for large telescopes.** *(The telescope has to be large for a person to sit inside the telescope to view the image.)*
Verbal, Logical

Address Misconceptions L2

Students may think that increasing the magnification of a reflecting telescope will improve the clarity of an image. This is not necessarily true. What can be viewed telescopically is limited by atmospheric conditions and the resolving power of the telescope. Any part of an image that is not clear at low magnification will appear only as a larger blur at higher magnification. Increasing magnification spreads out the light and decreases the brightness of the object. Astronomers describe telescopes not in terms of their magnification, but by the diameter of the objective mirror or lens, because it is this factor that determines both the light-gathering power and the resolving power of a telescope.
A good rule of thumb for amateur astronomers is that for every inch of aperture you can use up to 60 power. A three inch telescope would have a useful magnification of 180×.
Verbal

Go Online NSTA SCILINKS

Download a worksheet on telescopes for students to complete, and find additional teacher support from NSTA SciLinks.

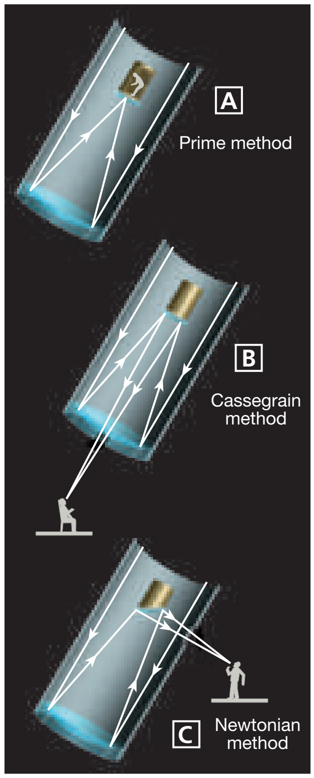


Figure 7 Viewing Methods with Reflecting Telescopes
A The prime method is only used with very large telescopes.
B The Cassegrain method is most commonly used. Note that a small hole in the center of the mirror allows light to pass through.
C This figure shows the Newtonian method.

Go Online SCILINKS NSTA
For: Links on telescopes
Visit: www.SciLinks.org
Web Code: cjn-7242

Reflecting Telescopes

Newton was bothered by chromatic aberration so he built telescopes that reflected light from a shiny surface—a mirror. Because reflected light is not dispersed into its component colors, the chromatic aberration is avoided. **Reflecting telescopes** use a concave mirror that focuses the light in front of a mirror, rather than behind it, like a lens. The mirror is generally made of glass that is finely ground and coated with a highly reflective material, usually an aluminum compound.

Because the focus of a reflecting telescope is in front of the mirror, an observer must be able to view the image without blocking too much incoming light. Figure 7A shows a viewing cage for the observer within the telescope. Figures 7B and 7C show that the observer can remain indoors. Most large telescopes employ more than one type.

Advantages of Reflecting Telescopes As you might guess, it's a huge task to produce a large piece of high-quality, bubble-free glass for refracting telescopes. **Most large optical telescopes are reflectors. Light does not pass through a mirror so the glass for a reflecting telescope does not have to be of optical quality.** In addition, a lens can be supported only around the edge, so it sags. Mirrors, on the other hand, can be supported fully from behind. One disadvantage of reflecting telescopes is that the secondary mirror blocks some light entering the telescope. Thus, a reflecting telescope with a 10-inch opening will not collect as much light as a 10-inch refractor.

Properties of Optical Telescopes Both refracting and reflecting telescopes have three properties that aid astronomers in their work: 1) light-gathering power, 2) resolving power, and 3) magnifying power. Light-gathering power refers to the telescope's ability to intercept more light from distant objects, thereby producing brighter images. Telescopes with large lenses or mirrors "see" farther into space than do those with small ones.

Another advantage of telescopes with large objectives is their greater resolving power, which allows for sharper images and finer detail. For example, with the naked eye, the Milky Way appears as a vague band of light in the night sky. But even a small telescope is capable of resolving, or separating it into, individual stars. Lastly, telescopes have magnifying power, which is the ability to make an object larger. Magnification is calculated by dividing the focal length of the objective by the focal length of the eyepiece. Thus, the magnification of a telescope can be changed by simply changing the eyepiece.

Reading Checkpoint *What is light-gathering power?*

Radio Telescopes

A

B

Figure 8 A The 43-meter Radio Telescope at Green Bank, West Virginia The dish acts like the mirror of a reflecting telescope, focusing radio waves onto the antenna. **B The Very Large Array Near Socorro, New Mexico** Twenty-seven identical antennas operate together to form this radio network.
Identifying ***What is a network of radio telescopes called?***

Detecting Invisible Radiation

As you learned earlier, sunlight is made up of more than just the radiation that is visible to our eyes. Gamma rays, X-rays, ultraviolet radiation, infrared radiation, and radio waves are also produced by stars. Photographic film that is sensitive to ultraviolet and infrared radiation has been developed. This extends the limits of our vision. However, most of this radiation cannot penetrate our atmosphere, so balloons, rockets, and satellites must transport cameras "above" the atmosphere to record it.

A narrow band of radio waves is able to penetrate the atmosphere. Measurement of this radiation is important because we can map the galactic distribution of hydrogen. Hydrogen is the main material from which stars are made.

Radio Telescopes The detection of radio waves is accomplished by big dishes called **radio telescopes,** shown in Figure 8A. In principle, the dish of one of these telescopes operates in the same manner as the mirror of an optical telescope. **A radio telescope focuses the incoming radio waves on an antenna, which absorbs and transmits these waves to an amplifier, just like a radio antenna.**

Because radio waves are about 100,000 times longer than visible radiation, the surface of the dish doesn't need to be as smooth as a mirror. Except for the shortest radio waves, a wire mesh is a good reflector. However, because radio signals from celestial sources are very weak, large dishes are necessary to intercept an adequate signal.

Radio telescopes have poor resolution, making it difficult to pinpoint the radio source. Pairs or groups of telescopes reduce this problem. When several radio telescopes are wired together, as shown in Figure 8B, the resulting network is called a radio interferometer.

Detecting Invisible Radiation

Build Science Skills

L2

Inferring Explain to students that radio waves are able to penetrate Earth's atmosphere and are used to map the distribution of hydrogen in the galaxy. Ask: **The largest radio telescope is 300 m (1,000 ft) in diameter. Why is a radio telescope this large an advantage?** *(Radio signals from celestial sources are very weak. This telescope is able to collect a larger number of signals because of its size.)* **This radio telescope was built in a depression in the landscape. Why was this location chosen?** *(This depression blocks human-made radio signals from the telescope.)*
Verbal, Logical

Facts and Figures

The Very Large Array consists of 27 radio antennas set up in a Y-shaped configuration. The site is located on the Plains of San Augustin 50 miles west of Socorro, New Mexico. Each antenna measures 25 m in diameter. When the antennas are combined electronically, they give an equivalent resolution of an antenna 36 km in diameter. The combination of the antennas has the sensitivity of a dish that is 130 m in diameter.

Answer to . . .

Figure 8 *a radio interferometer*

Reading Checkpoint *Light-gathering power refers to the telescope's ability to intercept more light from distant objects, thereby producing brighter images.*

Space Telescopes

Integrate Language Arts

L2

The Hubble Space Telescope The Hubble Space Telescope has provided spectacular images of the universe. This program also has experienced failures. Have students in groups research the Hubble Space Telescope project and create a computer presentation to share with their classmates. The Internet contains many photographs that can be included in the presentation.
Verbal, Interpersonal

Q & A

Q *Why do astronomers build observatories on mountaintops?*

A Observatories are most often located on mountaintops because sites above the densest part of the atmosphere provide better conditions for "seeing."

Advantages of Radio Telescopes Radio telescopes have some advantages over optical telescopes. They are much less affected by turbulence in the atmosphere, clouds, and the weather. No protective dome is required, which reduces the cost of construction. "Viewing" is possible 24 hours a day. More important, radio telescopes can "see" through interstellar dust clouds that obscure visible wavelengths. Radio signals from distant points in the universe pass unhindered through the dust, giving us an unobstructed view. Furthermore, radio telescopes can detect clouds of gases too cool to emit visible light. These cold gas clouds are important because they are the sites of star formation.

Radio telescopes are, however, hindered by human-made radio interference. While optical telescopes are placed on remote mountaintops to reduce interference from city lights, radio telescopes are often hidden in valleys to block human-made radio interference.

Radio telescopes have revealed such spectacular events as the collision of two galaxies. They led to the important discovery of quasars and pulsars.

Reading Checkpoint *Why can radio telescopes be used 24 hours a day?*

Space Telescopes

Have you ever seen a blurring effect caused by the movement of air on a hot summer day? That blurring effect also distorts the images produced by most telescopes on Earth. On a night when the stars twinkle, viewing is difficult because the air is moving rapidly. This causes the image to move about and blur.

Observatories are most often located on mountaintops. This is because sites above the densest part of the atmosphere provide better conditions for "seeing." At high elevations, there is less air to scatter and dim the incoming light. Also, there is less water vapor to absorb infrared radiation. Further, the thin air on mountaintops causes less distortion of the images being observed.

There is one other way to get around the distorting effects of Earth's atmosphere—send telescopes into space. **Space telescopes orbit above Earth's atmosphere and thus produce clearer images than Earth-based telescopes.**

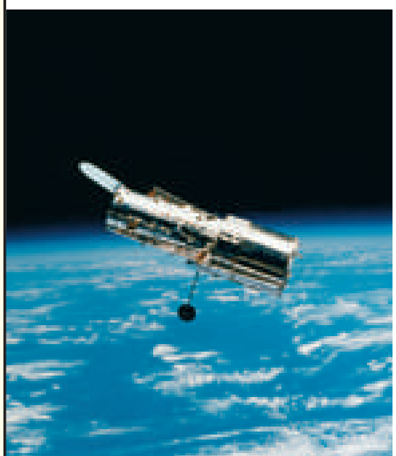


Figure 9 Hubble Space Telescope Hubble was deployed into Earth orbit by the space shuttle *Discovery*.

Hubble Space Telescope The first space telescope, built by NASA, was the Hubble Space Telescope, shown in Figure 9. Hubble was put into orbit around Earth in April 1990. This 2.4-meter space telescope has 10 billion times more light-gathering power than the human eye. Hubble has given us many spectacular images. For example, the

Hubble Space Telescope has provided images that clearly resolve the separation between Pluto and its moon, Charon. It has also provided data about planets that orbit other stars, the birth of stars, black holes, the age of the universe, and the expansion of the universe.

Other Space Telescopes

Other types of radiation are also affected by Earth's atmosphere. To study X-rays, NASA uses the Chandra X-Ray Observatory. This space telescope was launched in 1999. One of its main missions is to gather data about black holes—objects whose gravity is so strong that visible light cannot escape them. Another space telescope, the Compton Gamma-Ray Observatory, was used to study both visible light and gamma rays. In 2011, NASA plans to launch the James Webb Space Telescope to study infrared radiation. As Figure 10 shows, images obtained by different telescopes offer different information about the same object in space—in this case, the Milky Way galaxy. By studying all the images together, astronomers obtain a more thorough understanding of the galaxy.

Figure 10 Images of the Milky Way Galaxy These images were taken by different types of telescopes, including visible light, X-ray, gamma ray, and infrared.

Section 24.2 Assessment

Reviewing Concepts

1. How does a refracting telescope work?
2. How does a reflecting telescope differ from a refracting telescope?
3. Why are most large telescopes reflecting telescopes?
4. How do radio telescopes gather data?
5. Why do space telescopes obtain clearer images than Earth-based telescopes?

Critical Thinking

6. **Calculating** If a telescope has an objective with a focal length of 50 centimeters and an eyepiece with a focal length of 25 millimeter, what will be the magnification?
7. **Applying Concepts** Using the numbers from the previous question, would an eyepiece with a greater focal length increase or decrease magnification? Explain.

Connecting Concepts

Electromagnetic Radiation Recall the different types of electromagnetic radiation. Based on what you've learned in this section, would you recommend sending a telescope into space to study radio waves? Why or why not?

3 ASSESS

Evaluate Understanding L2

Have students write down the following types of telescopes: refracting, reflecting, and radio. Then, have students write down three facts about each telescope. Have students share their facts with the class.

Reteach L1

Use Figures 6, 7, and 8 to review how each of the these telescopes works.

Connecting Concepts

Sample answer: Radio waves can easily pass through Earth's atmosphere. Therefore, there is little advantage in sending a radio telescope into space.

Answer to . . .

Reading Checkpoint: *They do not need visible light to obtain images.*

Section 24.2 Assessment

1. The objective lens produces an image by bending light from a distant object so that the light converges at an area called the focus.
2. A reflecting telescope uses a concave mirror to produce an image. A refracting telescope uses a lens to bend or refract light.
3. Because light does not pass through a mirror, the glass for a reflecting telescope does not have to be of optical quality. In addition, a lens can be supported only around the edge, so it sags. Mirrors, on the other hand, can be supported fully from behind.
4. A radio telescope focuses the incoming radio waves on an antenna, which absorbs and transmits the waves to an amplifier.
5. Space telescopes orbit above Earth's atmosphere and thus produce clearer images than Earth-based telescopes.
6. Magnification is calculated by dividing the focal length of the objective by the focal length of the eyepiece. In this example, 500 mm ÷ 25 mm = 20; magnification would be 20 times.
7. An eyepiece with a greater focal length, such as 50 mm, would decrease magnification because 500 mm ÷ 50 mm = 10 times magnification.

Section 24.3

1 FOCUS

Section Objectives

24.7 **Explain** the structure of the sun.

24.8 **Describe** the physical features on the surface of the sun.

24.9 **Explain** how the sun produces energy.

Reading Focus

Build Vocabulary L2

LINCS There are several words in the vocabulary list that sound like other words students may be familiar with. Have students: **L**ist the parts that they know; **I**magine a picture; **N**ote a reminding sound-alike word; **C**onnect the terms; and **S**elf-test.

Reading Strategy L2

a. Answers will vary.
b. Answers will vary.
c. Answers will vary.
d. Answers will vary.

2 INSTRUCT

Build Reading Literacy L1

Refer to **p. 392D** in **Chapter 14**, which provides the guidelines for previewing.

Preview Before they read the section, have students skim the titles, headings, visual elements, and boldfaced type to preview how the text is organized.
Visual

24.3 The Sun

Reading Focus

Key Concepts

- What is the structure of the sun?
- What are the characteristics of features on the sun?
- How does the sun produce energy?

Vocabulary

- photosphere
- chromosphere
- corona
- solar wind
- sunspot
- prominence
- solar flare
- aurora
- nuclear fusion

Reading Strategy

Monitoring Your Understanding Preview the Key Concepts, topic headings, vocabulary, and figures in this section. Copy the table below, listing two things you expect to learn. After reading, fill in the table below, stating what you have learned about each item you listed.

What I Expect to Learn	What I Learned
a. ___?___	b. ___?___
c. ___?___	d. ___?___

The sun is one of the 100 billion stars that make up the Milky Way galaxy. Although the sun is of no significance to the universe as a whole, it is Earth's primary source of energy. Everything—from the fossil fuels we burn in our automobiles to the food that we eat—is ultimately derived from solar energy. The sun is also important to astronomers, since it is the only star whose surface we can study. Even with the largest telescopes, other stars appear only as points of light.

Because of the sun's brightness and its damaging radiation, it is not safe to observe it directly. However, a telescope can project its image on a piece of cardboard held behind the telescope's eyepiece. In this manner, the sun can be studied safely. This basic method is used in several telescopes around the world, which keep a constant watch of the sun. One of the finest is at the Kitt Peak National Observatory in southern Arizona, shown in Figure 11. It consists of an enclosure with moving mirrors that directs sunlight to an underground mirror. From the mirror, an image of the sun is projected to an observing room, where it is studied.

Figure 11 The McMath-Pierce Solar Telescope at Kitt Peak Near Tucson, Arizona Movable mirrors at the top follow the sun, reflecting its light down the sloping tunnel.

Compared to other stars, the sun is an "average star." However, on the scale of our solar system, it is truly gigantic. Its diameter is equal to 109 Earth diameters, or 1.35 million kilometers. Its volume is 1.25 million times as great as Earth's. Its mass is 332,000 times the mass of Earth and its density is only one quarter that of solid Earth.

Structure of the Sun

Because the sun is made of gas, no sharp boundaries exist between its various layers. **Keeping this in mind, we can divide the sun into four parts: the solar interior; the visible surface, or photosphere; and two atmospheric layers, the chromosphere and corona.** These parts are shown in Figure 12. The sun's interior makes up all but a tiny fraction of the solar mass. Unlike the outer three layers, the solar interior cannot be directly observed. Let's discuss the visible layers first.

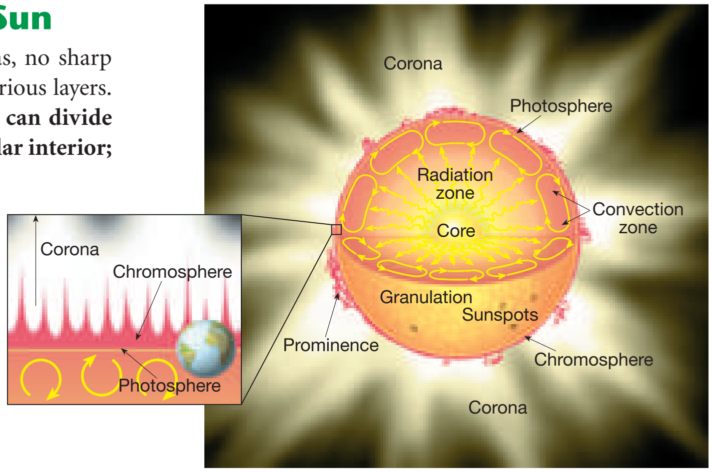


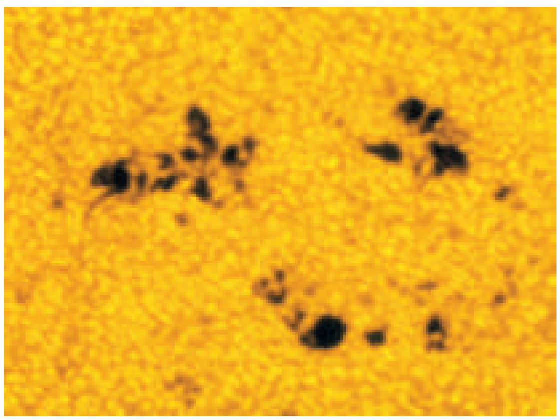
Figure 12 Structure of the Sun The sun can be divided into four parts: the solar interior, the photosphere, the chromosphere, and the corona.

Photosphere The **photosphere** (*photos* = light, *sphere* = a ball) radiates most of the sunlight we see and can be thought of as the visible "surface" of the sun. The photosphere consists of a layer of gas less than 500 kilometers thick. It is neither smooth nor uniformly bright, as the ancients had imagined.

When viewed through a telescope, the photosphere's grainy texture is apparent. This is the result of numerous relatively small, bright markings called granules, which are surrounded by narrow, dark regions, as shown in Figure 13. Granules are typically the size of Texas, and they owe their brightness to hotter gases that are rising from below. As this gas spreads, cooling causes it to darken and sink back into the interior. Each granule survives only 10 to 20 minutes. The combined motion of new granules replacing old ones gives the photosphere the appearance of boiling. This up-and-down movement of gas is called convection. Besides producing the grainy appearance of the photosphere, convection is believed to be responsible for the transfer of energy in the uppermost part of the sun's interior.

The composition of the photosphere is revealed by the dark lines of its absorption spectrum. Studies reveal that 90 percent of the sun's surface atoms are hydrogen, almost 10 percent are helium, and only minor amounts of the other detectable elements are present. Other stars also have high proportions of these two lightest elements, a fact we shall discuss later.

Figure 13 Granules Granules are the yellowish-orange patches on the photosphere. **Describing** ***Describe the movement of gases in the convection zone.***



Structure of the Sun

Address Misconceptions **L2**

Many students may think that since the sun is an enormous ball of gas it does not have a surface. The visible surface of the sun, the photosphere, is a layer of gas about 500 km thick. Most of the sunlight that we receive is from this layer. Although more light is emitted from the layer below the photosphere, that light is absorbed in the overlying layers of gas. Above the photosphere, the gas is less dense and thus unable to radiate much light. The photosphere is the layer that is dense enough to emit ample light yet has a density low enough to allow light to escape. Since the photosphere emits most of the light we see, it appears as the outermost surface of the sun.
Verbal

Customize for English Language Learners

Encourage English language learners to make a science glossary as they read the section. Suggest that they start with the vocabulary terms and then add any other new words they encounter. Encourage students to write brief definitions of each term and draw an illustration that helps them understand the term.

Answer to . . .

Figure 13 *Gases rise to the surface of the sun, cool, then sink back into the interior.*

Section 24.3 (continued)

Teacher Demo

Earth and Solar Winds L2

Purpose Students will observe how Earth is protected from solar winds.

Materials bar magnet, 2 sheets of notebook paper, iron filings, drinking straw

Procedure Cover the magnet with a sheet of paper. Fold the other sheet of paper in half. Sprinkle iron filings in the fold. Hold the paper about 15 cm from the magnet. Blow through the straw, directing the stream of air at the iron filings. The iron filings should be attracted to the magnet.

Expected Outcome Students will observe how a magnetic field attracts charged particles. The solar wind is composed of ionized or charged particles. Just as the iron filings are drawn to the magnet, the solar wind is attracted to Earth's magnetic field. Earth's magnetic field prevents the solar wind from reaching Earth's surface and bombarding it.
Visual, Logical

Figure 14 Chromosphere The chromosphere is a thin layer of hot gases that appears as a red rim around the sun.

Chromosphere Just above the photosphere lies the **chromosphere,** a relatively thin layer of hot gases a few thousand kilometers thick. The chromosphere is observable for a few moments during a total solar eclipse or by using a special instrument that blocks out the light from the photosphere. Under such conditions, it appears as a thin red rim around the sun. Because the chromosphere consists of hot, incandescent gases under low pressure, it produces an emission spectrum that is nearly the reverse of the absorption spectrum of the photosphere. One of the bright lines of hydrogen contributes a good portion of its total light and accounts for this sphere's red color.

Corona The outermost portion of the solar atmosphere, the **corona** (*corona* = crown) is very weak and, as with the chromosphere, is visible only when the brilliant photosphere is covered. This envelope of ionized gases normally extends a million kilometers from the sun and produces a glow about half as bright as the full moon.

At the outer fringe of the corona, the ionized gases have speeds great enough to escape the gravitational pull of the sun. The streams of protons and electrons that boil from the corona constitute the **solar wind.** This wind travels outward through the solar system at speeds up to 800 kilometers per second and eventually is lost to space. During its journey, the solar wind interacts with the bodies of the solar system, continually bombarding lunar rocks and altering their appearance. Although Earth's magnetic field prevents the solar winds from reaching our surface, these winds do affect our atmosphere, as we'll discuss later.

Studies of the energy emitted from the photosphere indicate that its temperature averages about 6000 K. Upward from the photosphere, the temperature unexpectedly increases, exceeding 1 million K at the top of the corona. Although the corona temperature is much higher than that of the photosphere, it radiates much less energy because of its very low density.

Reading Checkpoint *What is the solar wind?*

Facts and Figures

The high temperature of the corona is probably caused by sound waves generated by the convection motion of the photosphere. Just as boiling water makes noise, the energetic sound waves generated in the photosphere are believed to be absorbed by the gases of the corona and thereby raise their temperatures.

The Active Sun

The most conspicuous features on the surface of the sun are the dark regions. They were occasionally observed before the advent of the telescope, but were generally regarded as objects located somewhere between the sun and Earth. In 1610, Galileo concluded that these regions were part of the solar surface. From their motion, he deduced that the sun rotates on its axis about once a month. Later observations indicated that not all parts of the sun rotate at the same speed. The sun's equator rotates once in 25 days, while a location 70 degrees from the solar equator, whether north or south, requires 33 days for one rotation. Imagine if Earth rotated in a similar manner! The sun's nonuniform rotation is evidence of its gaseous nature.

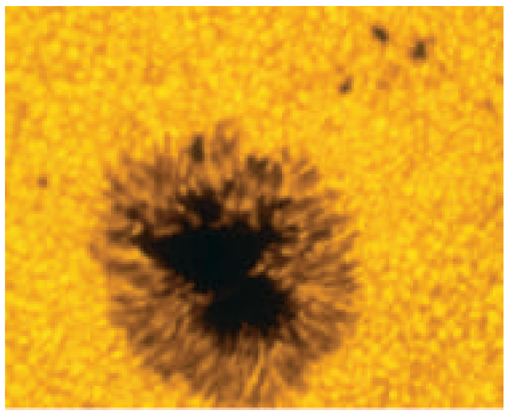
Sunspots What are those dark areas Galileo observed? The dark regions on the surface of the photosphere are called **sunspots.** As Figure 15 shows, an individual spot contains a black center rimmed by a lighter region. **Sunspots appear dark because of their temperature, which is about 1500 K less than that of the surrounding solar surface.** If these dark spots could be observed away from the sun, they would appear many times brighter than the full moon.

During the early nineteenth century, it was believed that a tiny planet named Vulcan orbited between Mercury and the sun. In the search for Vulcan an accurate record of sunspot occurrences was kept. Although the planet was never found, the sunspot data revealed that the number of sunspots observable varies in an 11-year cycle.

First, the number of sunspots increases to a maximum, with perhaps a hundred or more visible at a given time. Then their numbers gradually decline to a minimum, when only a few or even none are visible.

Figure 15 Sunspots A Sunspots often appear as groups of dark areas on the sun. **B** A close-up of an individual sunspot shows a black center surrounded by a lighter region.

A



B

The Active Sun

Build Science Skills

L2

Using Models Have students complete the following activity. Fill one of the empty soda bottles half full with water. Add 5 mL of glitter to the bottle of water. Place the washer on the mouth of the bottle. Dry the mouths of both bottles with a paper towel to be sure that the tape sticks. Place the mouth of the second bottle on top of the washer. Tape the two bottles together securely with duct tape. Swirl the two bottles several times. Then, turn the bottles upside down, placing the empty bottle on the table. The glitter demonstrates how fluids travel at different rates as the fluid moves through the funnel. Since the sun is not a solid body, the fluids are free to rotate at various speeds. So different parts of the sun rotate at different rates, just as they do in the bottles.
Kinesthetic, Visual

Facts and Figures

An interesting characteristic of sunspots was discovered by astronomer George Hale, for whom the Hale telescope is named. Hale found that the large sunspots are strongly magnetized, and when they occur in pairs, they have opposite magnetic poles. Also, every pair located in the same hemisphere is magnetized in the same manner. However, all pairs in the other hemisphere are magnetized in the opposite manner. At the beginning of each sunspot cycle, the polarity reverses. The cause of this change in polarity is not fully understood.

Answer to . . .

Reading Checkpoint *streams of protons and electrons that boil from the corona*

Use Visuals

L1

Figure 17 Have students examine the photograph. Ask: **Why do auroras occur near the polar regions instead of other locations on Earth?** *(The ionized particles in the solar flares are attracted to the north and south magnetic poles of Earth's magnetic field. The ions follow the magnetic field lines because a force is generated when they move with some component perpendicular to the lines, and the field lines mostly reach Earth at the magnetic poles.)* **Why do the auroral displays vary with the 11-year sunspot cycle?** *(Auroral displays are caused by sunspot activity.)*
Verbal, Logical

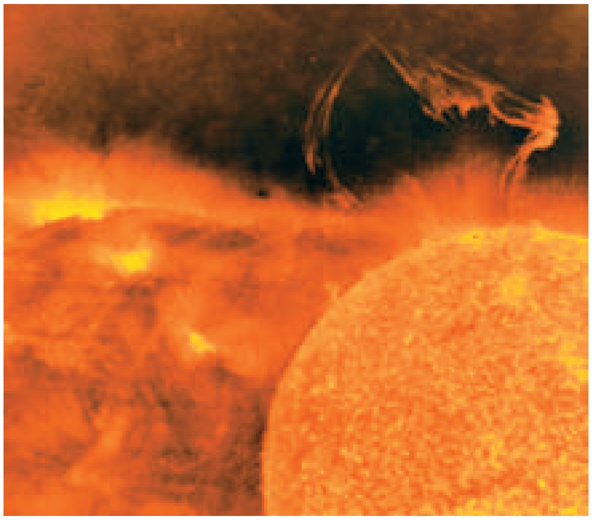


Figure 16 Solar Prominence Solar prominences are huge, arched structures, best observed when they are on the edge of the sun.

Prominences Among the more spectacular features of the active sun are prominences (*prominere* = to jut out). **Prominences** are huge cloudlike structures consisting of chromospheric gases. They often appear as great arches that extend well into the corona. Many prominences have the appearance of a fine tapestry and seem to hang motionless for days at a time. Others rise almost explosively away from the sun. These eruptive prominences reach speeds up to 1000 kilometers per second and may leave the sun entirely. **Prominences are ionized gases trapped by magnetic fields that extend from regions of intense solar activity.** Refer to Figure 16.

Solar Flares The most explosive events associated with sunspots are solar flares. **Solar flares** are brief outbursts that normally last about an hour and appear as a sudden brightening of the region above a sunspot cluster. **During their existence, solar flares release enormous amounts of energy, much of it in the form of ultraviolet, radio, and X-ray radiation.** At the same time, fast-moving atomic particles are ejected, causing the solar wind to intensify. Although a major flare could conceivably endanger the crew of a space flight, they are relatively rare. About a day after a large outburst, the ejected particles reach Earth, where they can affect long-distance radio communications.

The most spectacular effects of solar flares, however, are the **auroras,** also called the northern and southern lights. Following a strong solar flare, Earth's upper atmosphere near its magnetic poles is set aglow for several nights. The auroras appear in a wide variety of forms, one of which is shown in Figure 17. Sometimes the display looks like colorful ribbons moving with the breeze. At other times, the auroras appear as a series of luminous arcs or as a foglike glow. Auroral displays, like other solar activities, vary in intensity with the 11-year sunspot cycle.

Figure 17 Aurora Borealis or Northern Lights in Alaska The same phenomenon occurs toward the south pole, where it is called the aurora australis or southern lights.

Reading Checkpoint *What are solar flares?*

The Solar Interior

The interior of the sun cannot be observed directly. For that reason, all we know about it is based on information acquired from the energy it radiates and from theoretical studies. The source of the sun's energy was not discovered until the late 1930s.

Nuclear Fusion Deep in its interior, the sun produces energy by a process known as **nuclear fusion.** This nuclear reaction converts four hydrogen nuclei into the nucleus of a helium atom. Tremendous energy is released. **During nuclear fusion, energy is released because some matter is actually converted to energy, as shown in Figure 18.** How does this process work? Consider that four hydrogen atoms have a combined atomic mass of 4.032 atomic mass units (4 × 1.008) whereas the atomic mass of helium is 4.003 atomic mass units, or 0.029 less than the combined mass of the hydrogen. The tiny missing mass is emitted as energy according to Einstein's equation:

$$E = mc^2$$

E equals energy, *m* equals mass, and *c* equals the speed of light. Because the speed of light is very great (300,000 km/s), the amount of energy released from even a small amount of mass is enormous.

The conversion of just one pinhead's worth of hydrogen to helium generates more energy than burning thousands of tons of coal. Most of this energy is in the form of high-energy photons that work their way toward the solar surface. The photons are absorbed and reemitted many times until they reach a layer just below the photosphere. Here, convection currents help transport this energy to the solar surface, where it radiates through the transparent chromosphere and corona.

Only a small percentage of the hydrogen in the nuclear reaction is actually converted to energy. Nevertheless, the sun is consuming an estimated 600 million tons of hydrogen each second; about 4 million tons are converted to energy. As hydrogen is consumed, the product of this reaction—helium—forms the solar core, which continually grows in size.

Reading Checkpoint *What happens during the process of nuclear fusion?*

Go Online SCiLINKS NSTA

For: Links on nuclear fusion in the sun
Visit: www.SciLinks.org
Web Code: cjn-7243

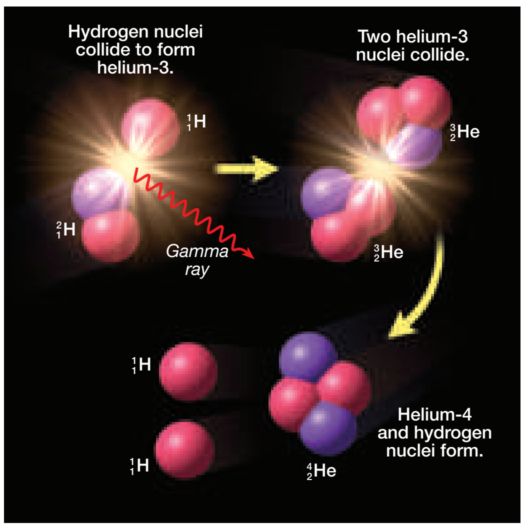


Figure 18 Nuclear Fusion During nuclear fusion, four hydrogen nuclei combine to form one helium nucleus. Some matter is converted to energy.

The Solar Interior

Use Visuals L1

Figure 18 Explain to students that the equation for nuclear fusion is:

$^{2}_{1}H + ^{1}_{1}H \rightarrow ^{3}_{2}He$ + gamma ray photon

$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + 2^{1}_{1}H$

The superscripts in these equations represent the mass numbers (number of protons plus neutrons), and the subscripts represent the atomic number (number of protons). Ask: **What is the next step in this reaction?** *(The hydrogen atoms, $^{1}_{1}H$, continue the chain reaction by striking two additional $^{2}_{1}H$ atoms.)*
Verbal, Logical

Integrate Physics L2

Nuclear Fusion as an Energy Source Using nuclear fusion as an electrical energy source could provide a limitless supply of electrical power. Constructing practical fusion reactors has proven to be difficult. Have students research nuclear fusion as a renewable energy source and prepare a report to present to the class. The report should contain promising techniques that scientists are currently investigating.
Verbal

Go Online NSTA SCiLINKS

Download a worksheet on nuclear fusion in the sun for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Reading Checkpoint *Solar flares are brief outbursts that normally last an hour or so, and appear as a sudden brightening of the region above a sunspot cluster.*

Reading Checkpoint *Some matter is converted to energy, and energy is released.*

Section 24.3 (continued)

3 ASSESS

Evaluate Understanding

L2

Have students draw and label a diagram of the sun. Have students include all of the applicable vocabulary words in the diagram. Then, have students explain how the sun gets its energy and what an aurora is.

Reteach

L1

Use Figure 12 to review the structure of the sun.

Math Practice

Solution

9. 4×10^6 tons $\div$ 6×10^8 tons = $0.0066 \times 100 = 0.7$ percent

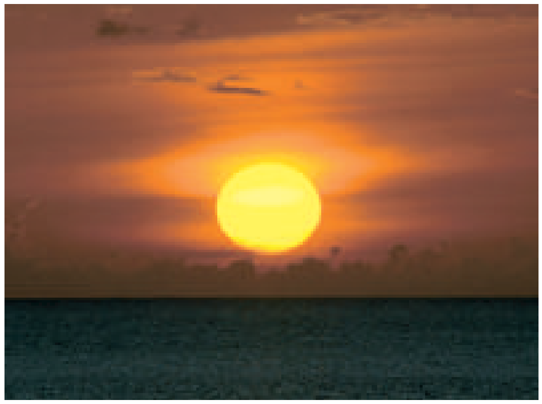


Figure 19 The sun is the source of more than 99 percent of all energy on Earth.

Just how long can the sun produce energy at its present rate before all of its hydrogen fuel is consumed? Even at the enormous rate of consumption, the sun, shown in Figure 19, has enough fuel to last easily another 100 billion years. However, evidence from other stars indicates that the sun will grow dramatically and engulf Earth long before all of its hydrogen is gone. It is thought that a star the size of the sun can exist in its present stable state for 10 billion years. As the sun is already 4.5 billion years old, it is "middle-aged."

To initiate nuclear fusion, the sun's internal temperature must have reached several million degrees. But what was the source of this heat? The solar system is believed to have formed from an enormous compressed cloud of dust and gases—mostly hydrogen. When gases are compressed, their temperature increases. All of the bodies in the solar system were compressed. However, the sun was the only one, because of its size, that became hot enough to trigger nuclear fusion. Astronomers currently estimate its internal temperature at 15 million K.

The planet Jupiter is basically a hydrogen-rich gas ball; if it were about 10 times more massive, it too might have become a star. The idea of one star orbiting another may seem odd, but recent evidence indicates that about 50 percent of the stars in the universe probably occur in pairs or multiples!

Section 24.3 Assessment

Reviewing Concepts

1. What is the structure of the sun?
2. Which layer of the sun can be thought of as its surface?
3. Describe some characteristics of features on the sun.
4. Are the same number of sunspots always present on the sun? Explain.
5. How does the sun produce energy?
6. How much longer will the sun likely exist in its present state?

Critical Thinking

7. **Relating Cause and Effect** Why do sunspots appear dark?
8. **Applying Concepts** What is the effect on Earth's atmosphere of a strong solar flare?

Math Practice

9. Of the 6×10^8 tons of hydrogen the sun consumes each second, about 4×10^8 tons are converted to energy. What percentage of the total energy consumed per second is converted to energy?

Section 24.3 Assessment

1. The sun contains the following parts: the solar interior, the photosphere, the chromosphere, and the corona.
2. the photosphere
3. Sunspots appear dark because of their temperature, which is about 1500 K less than that of the surrounding solar surface. Prominences are huge cloudlike structures of chromospheric gases. Solar flares release enormous amounts of energy.
4. No, because the number of sunspots varies in an 11-year cycle.
5. Deep in its interior, the sun produces energy by a process known as nuclear fusion, wherein four hydrogen nuclei are converted into the nucleus of a helium atom and tremendous energy is released.
6. The sun is estimated to last easily another 5 billion years.
7. Sunspots are somewhat cooler than the surrounding surface.
8. During a solar flare, fast-moving particles are ejected from the sun, increasing the solar wind. The ejected particles reach Earth and disturb long-distance radio communication. They also produce auroras.

earth as a SYSTEM

Solar Activity and Climatic Change

Some people believe that changes in solar activity relate to climatic change. The effect of such changes would seem direct and easily understood: Increases in solar output would cause the atmosphere to warm, and reductions would result in cooling. This notion is appealing because it can be used to explain climatic changes of any length or intensity.

Still, there is at least one major drawback: No major long-term variations in the total intensity of solar radiation have yet been measured. Such measurements were not even possible until satellite technology became available. Now that it is possible, we will need many years of records before we begin to sense how variable the sun really is.

Sunspot Cycles

Several theories for climatic change based on a variable sun relate to sunspot cycles. The most recognizable features on the surface of the sun are the dark regions called sunspots. See Figure 20. The number of sunspots seems to increase and decrease over a cycle of about 11 years. The graph in Figure 21 below shows the annual number of sunspots, beginning in the early 1700s. However, this pattern is not always regular.

There have been long periods when sunspots have been absent or nearly absent. These events correspond closely with cold periods in Europe and North America. In contrast, periods of high sunspot activity have been associated with warmer times in these regions.

Conflicting Evidence

Because of these data, some scientists have suggested that changes in solar activity are an important cause of climatic change. But other scientists seriously question this notion. Their hesitation stems in part from investigations using different climatic records from around the world that failed to find a significant relationship between solar activity and climate. Even more troubling is that there is no way to test the relationship.

Figure 20 Dark regions on the surface of the sun are called sunspots.

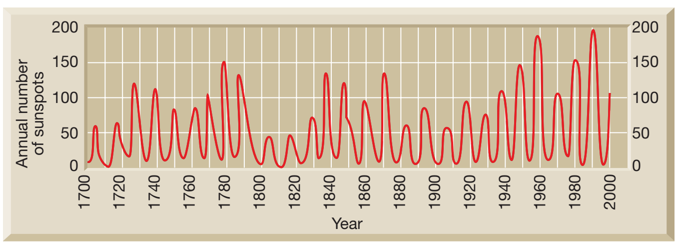


Figure 21 Mean Annual Sunspot Numbers

earth as a SYSTEM

Solar Activity and Climatic Change L2

Background

A National Aeronautics and Space Administration (NASA) computer climate model suggests that low solar activity from the 1400s to the 1700s could have triggered the "Little Ice Age" in North America and Europe. Changes in the sun's energy were one of the biggest factors influencing climatic changes during this time period. While solar activity primarily influenced temperature variations during the Middle Ages, this is not true today. The accumulation of greenhouse gases in the atmosphere, caused by human activities, is the primary catalyst for temperature changes today.

Teaching Tip

Have students research information available from NASA, National Oceanic and Atmospheric Administration (NOAA), and other reliable sources on the relationship between Earth temperature and solar activity. Students should write a short report detailing the information they have found.
Verbal

Studying the Sun 691

Section 25.1

1 FOCUS

Section Objectives

25.1 **Describe** what astronomers can learn by studying star properties.
25.2 **Explain** how distance affects parallax.
25.3 **List** the factors that determine a star's apparent magnitude.
25.4 **Describe** the relationship shown on a Hertzprung-Russell diagram.

Reading Focus

Build Vocabulary L2

Word Parts and Roots Have students look up the prefix *bi-* to help them understand what *binary* means. (*"two," "having two distinct parts"*) Have them look up the origin of *nova* and relate it to its meaning. (*from the Latin* novus, *meaning "new"; refers to a bright star that suddenly appears in the sky*) Also have them look up the meaning of *nebulous* and relate it to the meaning of *nebula*. (*"lacking definite form or limits"; describes the appearance of a nebula*)

Reading Strategy L2

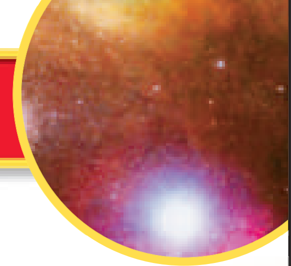
Possible answers:
a. What information does the H-R diagram show?
b. absolute magnitude and temperature
c. What is the largest group of stars on the H-R diagram?
d. the main sequence

2 INSTRUCT

Integrate Language Arts L2

Greek Mythology Tell students that many of the constellations were named by the ancient Greeks after characters in stories. Other peoples, such as Native Americans, had different names and stories associated with various star patterns. Ask students to each research a different constellation and write a paragraph describing the story associated with it. Students can also make up their own patterns and stories if they wish.
Verbal

25.1 Properties of Stars



Reading Focus

Key Concepts

- What can we learn by studying star properties?
- How does distance affect parallax?
- What factors determine a star's apparent magnitude?
- What relationship is shown on a Hertzsprung-Russell diagram?

Vocabulary

- constellation
- binary star
- light-year
- apparent magnitude
- absolute magnitude
- main-sequence star
- red giant
- supergiant
- Cepheid variable
- nova
- nebulae

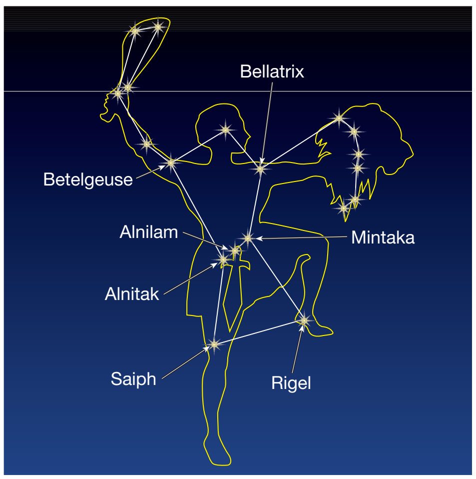
Reading Strategy

Previewing Copy the table below. Before you read, write two questions about the Hertzsprung-Russell diagram on page 704. As you read, write answers to your questions.

Questions about the Hertzsprung-Russell Diagram	
Question	**Answer**
a. ?	b. ?
c. ?	d. ?

The star Proxima Centauri is about 100 million times farther away from Earth than the moon. Yet, besides the sun, it is the closest star to Earth. The universe is incomprehensibly large. What is the nature of this vast universe? Do stars move, or do they remain in one place? Does the universe extend infinitely in all directions, or does it have boundaries? This chapter will answer these questions by examining the universe and the most numerous objects in the night sky—the stars.

Figure 1 Orion The constellation Orion was named for a hunter.



As early as 5000 years ago, people became fascinated with the star-studded skies and began to name the patterns they saw. These patterns of stars, called **constellations,** were named in honor of mythological characters or great heroes, such as Orion, shown in Figure 1.

Although the stars that make up a constellation all appear to be the same distance from Earth, some are many times farther away than others. So, the stars in a particular constellation are not associated with one another in any physical way.

Today 88 constellations are recognized. They are used to divide the sky into units, just as state boundaries divide the United States. Every star in the sky is in, but is not necessarily part of, one of these constellations. Therefore, constellations can be used as a "map" of the night sky.

Characteristics of Stars

A great deal is known about the universe beyond our solar system. This knowledge hinges on the fact that stars, and even gases in the "empty" space between stars, radiate energy in all directions into space. The key to understanding the universe is to collect this radiation and unravel the secrets it holds. Astronomers have devised many ways to do just that. We will begin by examining some properties of stars, such as color, temperature, and mass.

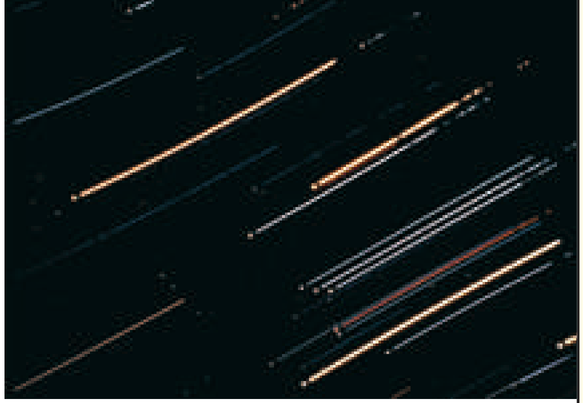


Figure 2 Stars of Orion This time-lapse photograph shows stars as streaks across the night sky as Earth rotates. The streaks clearly show different star colors.

Star Color and Temperature

Study the stars in Figure 2 and note their color. **Color is a clue to a star's temperature.** Very hot stars with surface temperatures above 30,000 K emit most of their energy in the form of short-wavelength light and therefore appear blue. Red stars are much cooler, and most of their energy is emitted as longer-wavelength red light. Stars with temperatures between 5000 and 6000 K appear yellow, like the sun.

Binary Stars and Stellar Mass

In the early nineteenth century, astronomers discovered that many stars orbit each other. These pairs of stars, pulled toward each other by gravity, are called **binary stars.** More than 50 percent of the stars in the universe may occur in pairs or multiples.

Binary stars are used to determine the star property most difficult to calculate—its mass. The mass of a body can be calculated if it is attached by gravity to a partner. This is the case for any binary star system. As shown in Figure 3, binary stars orbit each other around a common point called the center of mass. For stars of equal mass, the center of mass lies exactly halfway between them. If one star is more massive than its partner, their common center will be closer to the more massive one. If the sizes of their orbits are known, the stars' masses can be determined.

Reading Checkpoint *What is a binary star system?*

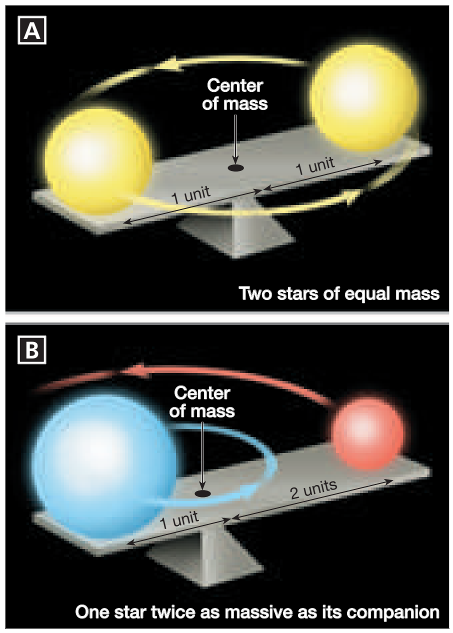


Figure 3 Common Center of Mass
A For stars of equal mass, the center of mass lies in the middle. **B** A star twice as massive as its partner is twice as close to the center of mass. It therefore has a smaller orbit than its less massive partner.

Characteristics of Stars

Address Misconceptions L2

Students often think that all stars are found alone in space, as the sun is. Explain that most stars are actually in pairs or larger groups. Fewer than half are single stars. Many familiar stars in the sky are actually multiple star systems. For example, the very bright star Sirius A has a dimmer companion, Sirius B. Alpha Centauri is actually a double star and forms a triple system along with Proxima Centauri.
Verbal

Teacher Demo

Binary Star Motion

L2

Purpose Students observe how stars of equal and different masses revolve around a common center of mass.

Materials string, tape, 2 tennis balls, pencil, table tennis ball

Procedure Use string and tape to hang a tennis ball from one end of a pencil. Hang another tennis ball from the other end of the pencil. Tell students that the balls represent stars and the pencil represents gravity holding them together. Tie another string to the center of the pencil so that the pencil is balanced when hung from the string. Twist the string so that the balls rotate around each other. Ask students what figure in the text this represents. *(Figure 3A)* Ask them to predict what will happen if one of the balls is replaced with a smaller one. *(The center of mass will be closer to the large ball, and it will move less.)* Replace one tennis ball with a table tennis ball. Adjust the string on the pencil until it balances and sets the system rotating. Ask students what figure in the text this represents. *(Figure 3B)*

Expected Outcome The tennis balls will revolve around an equidistant center of mass. The tennis ball and table tennis ball will revolve around a center of mass close to the tennis ball.
Visual, Logical

Answer to . . .

Reading Checkpoint *A binary star system is made up of two stars that orbit each other.*

Customize for English Language Learners

Write each of the vocabulary words at the top of an index card and post them on a word wall. As students read the section, discuss the definitions of each term and add them to the index cards. Work with students to help them organize the words into groups based on their scientific meanings. Revisit the word wall and use it as an interactive tool to help students learn the terms. Refer to the words as often as you can and incorporate them into homework or other assignments.

Measuring Distances to Stars

Use Visuals

L1

Figure 4 Use this figure to explain how parallax works. Emphasize that the drawing is not to scale; the star would actually be much farther away and the parallax angle very small. Ask: **What does the simulated photograph at the top left show?** *(It shows the star as seen from Earth's original position.)* **What does the simulated photograph at the bottom left show?** *(It shows the star as seen from Earth 6 months later.)* **How is the parallax angle related to the distance between the star and Earth?** *(The farther away the star is, the smaller the angle.)*
Visual, Logical

Address Misconceptions

L2

Students are often confused by the term *light-year* and think that it is a unit of time. Explain again that the "year" refers to the time it takes for light to travel the distance known as a *light-year*. Have students calculate the distance to Proxima Centauri in kilometers.
(4.3 light-years × 9.5 × 10^{12} km =
≈ 41 × 10^{12} km)
Logical

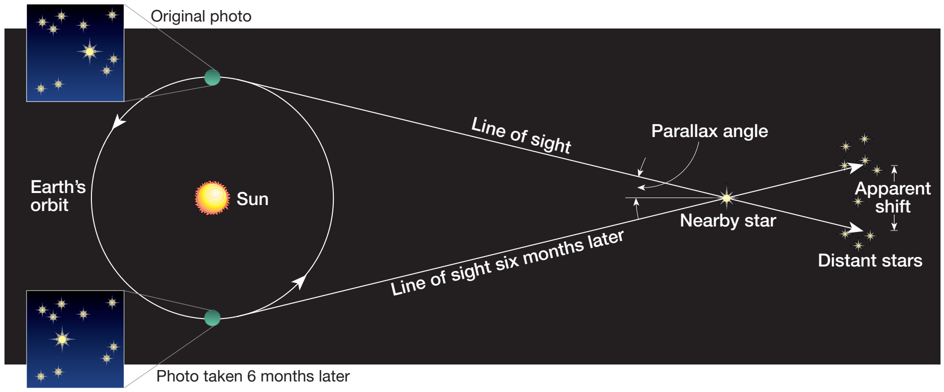


Figure 4 Parallax The parallax angle shown here is exaggerated to illustrate the principle. Because the distances to even the nearest stars are huge, astronomers work with very small angles.
Relating Cause and Effect *What caused the star to appear to shift?*

Measuring Distances to Stars

Although measuring the distance to a star is very difficult, astronomers have developed some methods of determining stellar distances.

Parallax The most basic way to measure star distance is parallax. Parallax is the slight shifting in the apparent position of a nearby star due to the orbital motion of Earth. Parallax is determined by photographing a nearby star against the background of distant stars. Then, six months later, when Earth has moved halfway around its orbit, a second photograph is taken. When these photographs are compared, the position of the nearby star appears to have shifted with respect to the background stars. Figure 4 shows this shift and the resulting parallax angle.

The nearest stars have the largest parallax angles, while those of distant stars are too small to measure. In fact, all parallax angles are very small. The parallax angle to the nearest star (besides the sun), Proxima Centauri, is less than 1 second of arc, which equals 1/3600 of a degree. To put this in perspective, fully extend your arm and raise your little finger. Your finger is roughly 1 degree wide. Now imagine tracking a movement that is only 1/3600 as wide as your finger.

In principle, the method used to measure stellar distances may seem simple. But in practice, measurements are greatly complicated because of the tiny angles involved and because the sun, as well as the star being measured, also move through space. Even with today's technology, parallax angles for only a few thousand of the nearest stars are known with certainty.

Light-Year Distances to stars are so large that units such as kilometers or astronomical units are often too hard to use. A better unit to express stellar distance is the **light-year,** which is the distance light travels in one year—about 9.5 × 10^{12} or 9.5 trillion kilometers. Proxima Centauri is about 4.3 light-years away from the sun.

Reading Checkpoint *What is a light-year?*

Stellar Brightness

The measure of a star's brightness is its magnitude. The stars in the night sky have an assortment of sizes, temperatures, and distances, so their brightnesses vary widely.

Apparent Magnitude Some stars may appear dimmer than others only because they are farther away. A star's brightness as it appears from Earth is called its **apparent magnitude.** **Three factors control the apparent brightness of a star as seen from Earth: how big it is, how hot it is, and how far away it is.**

Astronomers use numbers to rank apparent magnitude. The larger the number is, the dimmer the star. Just as we can compare the brightness of a 50-watt bulb to that of a 100-watt bulb, we can compare the brightness of stars having different magnitudes. A first-magnitude star is about 100 times brighter than a sixth-magnitude star. Therefore, two stars that differ by 5 magnitudes have a ratio in brightness of 100 to 1. It follows, then, that the brightness ratio of two stars differing by only one magnitude is about 2.5. A star of the first magnitude is about 2.5 times brighter than a star of the second magnitude.

Reading Checkpoint *What is apparent magnitude?*

Absolute Magnitude Astronomers are also interested in how bright a star actually is, or its **absolute magnitude.** Two stars of the same absolute magnitude usually do not have the same apparent magnitude because one may be much farther from us than the other. The one that is farther away will appear dimmer. To compare their absolute brightness, astronomers determine what magnitude the stars would have if they were at a standard distance of about 32.6 light-years. For example, the sun, which has an apparent magnitude of −26.7, would, if located at a distance of 32.6 light-years, have an absolute magnitude of about 5. Stars with absolute magnitude values lower than 5 are actually brighter than the sun. Because of their distance, however, they appear much dimmer. Table 1 lists the absolute and apparent magnitudes of some stars as well as their distances from Earth.

Table 1 Distance, Apparent Magnitude, and Absolute Magnitude of Some Stars

Name	Distance (light-years)	Apparent Magnitude*	Absolute Magnitude*
Sun	NA	−26.7	5.0
Alpha Centauri	4.27	0.0	4.4
Sirius	8.70	−1.4	1.5
Arcturus	36	−0.1	−0.3
Betelgeuse	520	0.8	−5.5
Deneb	1600	1.3	−6.9

*The more negative, the brighter; the more positive, the dimmer.

Reading Checkpoint *What is absolute magnitude?*

Stellar Brightness

Build Reading Literacy L1

Refer to **p. 216D** in **Chapter 8,** which provides guidelines for comparing and contrasting.

Compare and Contrast Have students create and fill in a table to compare and contrast apparent and absolute magnitude. They should consider what determines the value of apparent and absolute magnitude and whether each one is a relative value or an absolute value.
Visual

Teacher Demo

Apparent and Absolute Magnitude L2

Purpose Students observe the difference between apparent and absolute magnitude.

Materials 2 equally bright flashlights, 1 dimmer flashlight

Procedure Place two equally bright flashlights near the front of the class, one as close to the students as possible and one as far away as possible. Dim the lights and turn the flashlights on. Ask: **Which flashlight has the greater apparent magnitude?***(the closer one)* **Which flashlight has the lower apparent magnitude?** *(the more distant one)* Place the two flashlights side by side. Ask: **How do the flashlights' apparent magnitudes compare?** *(They are the same.)* **How do the flashlights' absolute magnitudes compare?** *(They are the same.)* Replace one flashlight with a dimmer one. Ask: **Which flashlight has the greater apparent magnitude?** *(the brighter one)* **Which flashlight has the greater absolute magnitude?** *(the brighter one)*

Expected Outcome Students will observe how distance and brightness affect apparent and absolute magnitude.
Visual

Facts and Figures

Stars were first classified according to their brightness around the second century B.C., when the Greek astronomer Hipparchus classified about 1000 stars into six categories. In 1989, the European Space Agency launched the satellite Hipparcos (High Precision Parallax Collecting Satellite). Hipparcos used parallax to measure the distances to all visible stars within about 150 light-years of the sun. The accuracy of the measurements was about 2 milliarcseconds, or within 10 percent.

Answer to . . .

Figure 4 *Earth moved in its orbit.*

Reading Checkpoint *the distance light travels in one year—about 9.5 trillion km*

Reading Checkpoint *the brightness of a star as seen from Earth*

Reading Checkpoint *how bright a star actually is*

Hertzsprung-Russell Diagram

Address Misconceptions **L2**

Students often think that the H-R diagram is a star chart that shows the locations of stars in the sky. Emphasize that the H-R diagram is a graph that shows the characteristics of stars. Go over the units shown on the axes so that students understand why it is a graph. Explain that the stars are shown different sizes on the graph for illustration only. Also explain that an H-R diagram can be used to plot any sample of stars.
Visual

Use Visuals **L1**

Figure 5 Use this diagram to explain the main groups of stars on the H-R diagram. Ask: **To what group of stars does the sun belong?** *(It belongs to the main sequence.)* **How are absolute magnitude and temperature related within the main sequence?** *(As absolute magnitude increases, so does temperature.)* **What types of stars have high absolute magnitude but low temperature?** *(giants and supergiants)* **What types of stars have low absolute magnitudes and medium temperatures?** *(white dwarfs)*
Visual, Logical

Hertzsprung-Russell Diagram

Early in the twentieth century, Einar Hertzsprung and Henry Russell independently developed a graph used to study stars. It is now called a Hertzsprung-Russell diagram (H-R diagram). **A Hertzsprung-Russell diagram shows the relationship between the absolute magnitude and temperature of stars.** By studying H-R diagrams, we learn a great deal about the sizes, colors, and temperatures of stars.

In the H-R diagram shown in Figure 5, notice that the stars are not uniformly distributed. About 90 percent are **main-sequence stars** that fall along a band that runs from the upper-left corner to the lower-right corner of the diagram. As you can see, the hottest main-sequence stars are the brightest, and the coolest main-sequence stars are the dimmest.

The brightness of the main-sequence stars is also related to their mass. The hottest blue stars are about 50 times more massive than the sun, while the coolest red stars are only 1/10 as massive. Therefore, on the H-R diagram, the main-sequence stars appear in decreasing order, from hotter, more massive blue stars to cooler, less massive red stars.

Above and to the right of the main sequence in the H-R diagram lies a group of very bright stars called **red giants.** The size of these giants can be estimated by comparing them with stars of known size that have the same surface temperature. Objects with equal surface temperatures radiate the same amount of energy per unit area. Therefore, any difference in the brightness of two stars having the same surface temperature is due to their relative sizes. Some stars are so large that they are called **supergiants.** Betelgeuse, a bright red supergiant in the constellation Orion, has a radius about 800 times that of the sun.

Stars in the lower-central part of the H-R diagram are much fainter than main-sequence stars of the same temperature. Some probably are no bigger than Earth. This group is called white dwarfs, although not all are white.

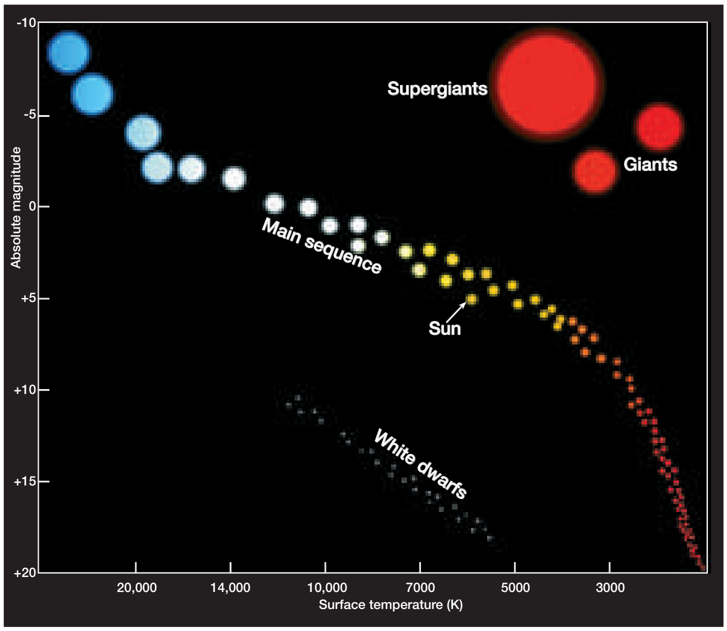


Figure 5 Hertzsprung-Russell Diagram In this idealized chart, stars are plotted according to temperature and absolute magnitude.

Facts and Figures

Einar Hertzsprung was born in 1873 in Denmark. He worked as a chemist before switching to studying astronomy. In 1912, he discovered that for most stars temperature is closely related to absolute magnitude. Before this discovery, astronomers had thought that stars could have any combination of temperature and absolute magnitude.

Henry Norris Russell was born in 1877 in the United States. While working in England in 1921, Russell independently found the same relationship that Hertzsprung had. Hertzsprung continued to work into his nineties. Russell spent six decades at Princeton University.

Soon after the first H-R diagrams were developed, astronomers realized their importance in interpreting stellar evolution. Just as with living things, a star is born, ages, and dies. After considering some variable stars and the nature of interstellar matter, we'll return to the topic of stellar evolution.

Variable Stars Stars may fluctuate in brightness. Some stars, called **Cepheid variables,** get brighter and fainter in a regular pattern. The interval between two successive occurrences of maximum brightness is called a light period. In general, the longer the light period of a Cepheid, the greater its absolute magnitude is. Once the absolute magnitude is known, it can be compared to the apparent magnitude of the Cepheid. Measuring Cepheid variable periods is an important means of determining distances within our universe.

A different type of variable is associated with a **nova,** or sudden brightening of a star. During a nova eruption, the outer layer of the star is ejected at high speed. A nova, shown in Figure 6, generally reaches maximum brightness in a few days, remains bright for only a few weeks, then slowly returns in a year or so to its original brightness. Only a small amount of its mass is lost during the flare-up. Some stars have experienced more than one such event. In fact, the process probably occurs repeatedly.

Scientists think that novas occur in binary systems consisting of an expanding red giant and a nearby hot white dwarf. Hydrogen-rich gas from the oversized giant is transferred by gravity to the white dwarf. Eventually, the added gas causes the dwarf to ignite explosively. Such a reaction rapidly heats and expands the outer layer of the hot dwarf to produce a nova. In a relatively short time, the white dwarf returns to its prenova state, where it remains inactive until the next buildup occurs.

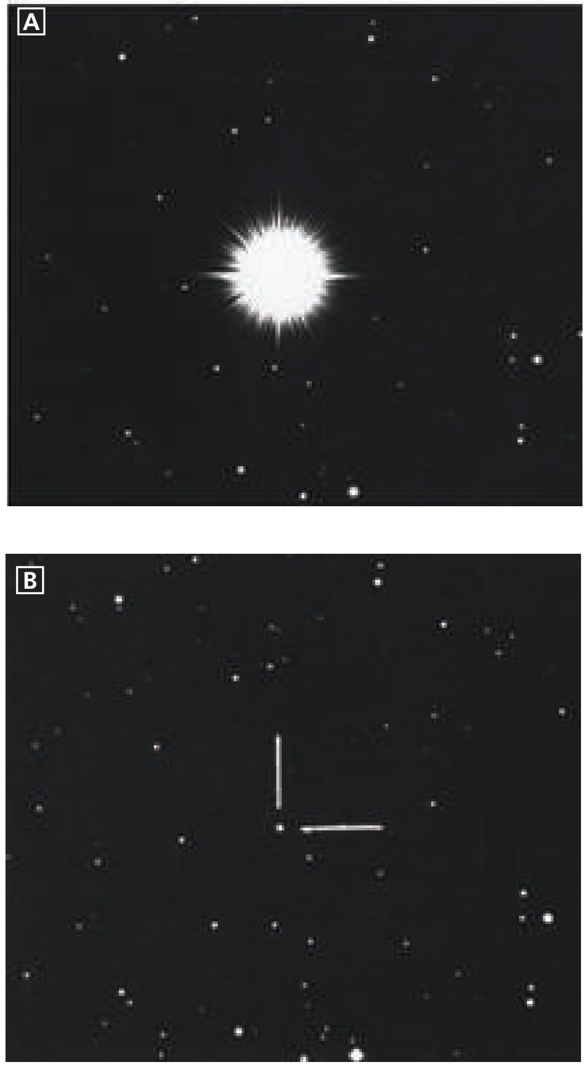


Figure 6 Nova These photographs, taken two months apart, show the decrease in brightness that follows a nova flare-up.

Build Science Skills L2

Relating Cause and Effect
Go through the cyclical process that may cause some novas to flare up repeatedly. Ask: **What is the first step in the process?** *(Hydrogen-rich gas is transferred from a red giant to a white dwarf.)* **What effect does this have on the white dwarf?** *(The gas eventually causes the dwarf to ignite explosively.)* **What effect does this reaction have on the white dwarf?** *(The outer layer is heated and expands, producing a nova.)* Have students draw cycle diagrams of the entire process.
Logical

Build Reading Literacy L1

Refer to **p. 92D** in **Chapter 4,** which provides guidelines for this using context clues strategy.

Using Context Clues Tell students that the term *nova* derives from the Latin word *novus*, meaning new. Ask students to explain why the term nova got this name. *(The sudden brightening of an existing star may have been interpreted as the creation of a new star.)* Encourage students to look up words and consider their roots as they encounter new vocabulary.
Verbal

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Section 25.1 (continued)

3 ASSESS

Evaluate Understanding L2

Ask students to write a summary paragraph explaining how scientists use parallax to determine the difference to nearby stars.

Reteach L1

Use Figure 5 to review how different types of stars are plotted on an H-R diagram.

Writing in Science

Student Web sites should explain how stars are plotted on the H-R diagram according to absolute magnitude and temperature. Web sites should also include definitions of key terms and a color key explaining the relationship between star color and temperature.

Figure 7 Dark Nebula The Horsehead Nebula is found in the constellation Orion.

Interstellar Matter Between existing stars is "the vacuum of space." However, it is not a pure vacuum, for there are clouds of dust and gases known as **nebulae.** If this interstellar matter is close to a very hot star, it will glow and is called a bright nebula. The two main types of bright nebulae are emission nebulae and reflection nebulae.

Emission nebulae consist largely of hydrogen. They absorb ultraviolet radiation emitted by a nearby hot star. Because these gases are under very low pressure, they emit this energy as visible light. This conversion of ultraviolet light to visible light is known as fluorescence. You can see this effect in fluorescent lights. Reflection nebulae, as the name implies, merely reflect the light of nearby stars. Reflection nebulae are thought to be composed of dense clouds of large particles called interstellar dust.

Some nebulae are not close enough to a bright star to be lit up. They are called dark nebulae. Dark nebulae, such as the one shown in Figure 7, can easily be seen as starless regions when viewing the Milky Way.

Although nebulae appear very dense, they actually consist of thinly scattered matter. Because of their enormous size, however, their total mass may be many times that of the sun. Astronomers study nebulae because stars and planets form from this interstellar matter.

Section 25.1 Assessment

Reviewing Concepts

1. What can astronomers learn by studying a star's color?
2. Binary stars can be used to establish what property of stars?
3. How does distance affect parallax?
4. What factors determine a star's apparent magnitude?
5. The H-R diagram shows the relationship between what two factors?

Critical Thinking

6. **Problem Solving** How many times brighter is a star with a magnitude of 7 than a star with a magnitude of 12?
7. **Inferring** Scientists think that only a small amount of a star's mass is lost during a nova. Based on what you have learned about novas, infer what evidence scientists use to support this theory.

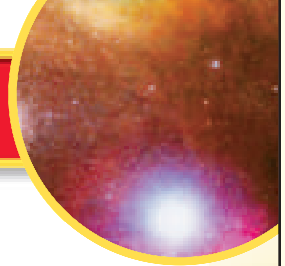
Writing in Science

Web Site Make an educational Web site about the H-R diagram for younger students. Use Figure 5 as a guide. Include a color key and other elements to help clarify concepts such as star temperature, the Kelvin scale, and absolute magnitude.

Section 25.1 Assessment

1. Astronomers can learn about a star's temperature by studying its color.
2. Binary stars can be used to establish a star's mass.
3. The nearest stars have the largest parallax angles, while the parallax angles of distant stars are too small to measure.
4. Three factors determine the apparent magnitude of a star: how big it is, how hot it is, and how far away it is.
5. absolute magnitude and the temperature of stars
6. The magnitude 7 star is 100 times brighter.
7. Following the nova flare-up, the star returns to its prenova state. If a great amount of mass had been lost, this would not be possible, nor would it be possible for the star to experience more than one nova eruption.

25.2 Stellar Evolution



Reading Focus

Key Concepts

- What stage marks the birth of a star?
- Why do all stars eventually die?
- What stages make up the sun's life cycle?

Vocabulary

- protostar
- supernova
- white dwarf
- neutron star
- pulsar
- black hole

Reading Strategy

Sequencing Copy the flowchart below. As you read, complete it to show how the sun evolves. Expand the chart to show the evolution of low-mass and high-mass stars.

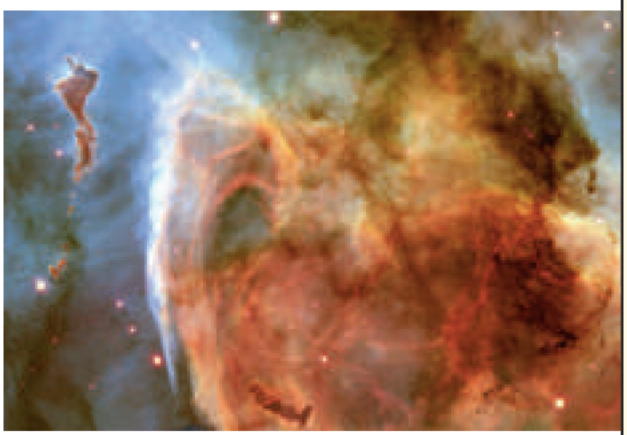
Evolution of Sun → a. ? → b. ?

Determining how stars are born, age, and then die was difficult because the life of a star can span billions of years. However, by studying stars of different ages, astronomers have been able to piece together the evolution of a star. Imagine that an alien from outer space lands on Earth. This alien wants to study the stages of human life. By examining a large number of humans, the alien observes the birth of babies, the activities of children and adults, and the death of elderly people. From this information, the alien then attempts to put the stages of human development into proper sequence. Based on the number of humans in each stage of development, the alien would conclude that humans spend more of their lives as adults than as children. In a similar way, astronomers have pieced together the story of stars.

Figure 8 Nebula Dark, cool clouds full of interstellar matter are the birthplace of stars.

Star Birth

The birthplaces of stars are dark, cool interstellar clouds, such as the one in Figure 8. These nebulae are made up of dust and gases. In the Milky Way, nebulae consist of 92 percent hydrogen, 7 percent helium, and less than 1 percent of the remaining heavier elements. For some reason not yet fully understood, some nebulae become dense enough to begin to contract. A shock wave from an explosion of a nearby star may trigger the contraction. Once the process begins, gravity squeezes particles in the nebula, pulling every particle toward the center. As the nebula shrinks, gravitational energy is converted into heat energy.



Section 25.2

1 FOCUS

Section Objectives

25.5 **Identify** which stage marks the birth of a star.
25.6 **Explain** why all stars eventually die.
25.7 **List** the stages of the sun's life cycle.

Reading Focus

Build Vocabulary L2

Concept Map As students read the section, have them make a concept map showing how the vocabulary terms are related. The concept map should show how a star changes during its lifetime.

Reading Strategy L2

a. cloud of dust and gases (nebula stage)
b. protostar stage

2 INSTRUCT

Star Birth

Build Science Skills L2

Using Analogies ACTIVITY
Show students a series of photographs of people of different ages. Ask them to put the photos in order by age. Then, show students a series of photographs of the life cycle of an insect, such as a butterfly, that undergoes complete metamorphosis. Ask them to put the photos in order by age. Ask: **Why was the second series was harder to sequence than the first one?** *(You can't easily tell by looking at the photos which stage comes in what order.)* Point out that astronomers have the same problem with stars. It's not obvious just from looking at various stages of stars how old they are.
Logical, Visual

Integrate Physics L2

Fission and Fusion Review the concepts of fission and fusion with students. During fission, atomic nuclei are split apart to make smaller nuclei. This is the process used in nuclear power plants. During fusion, atomic nuclei combine to make larger nuclei. Sustained fusion occurs only within stars. Main-sequence stars fuse four hydrogen nuclei to form a helium nucleus. The helium nucleus has slightly less mass than the hydrogen nuclei. The remaining mass is converted into energy. Hotter stars can produce carbon and other elements by fusion.
Logical, Verbal

Build Reading Literacy L1

Refer to **p. 392D** in **Chapter 14**, which provides guidelines for previewing.

Preview Before they read the section, have students skim the headings, visuals, and boldfaced words to preview how the text is organized.
Verbal, Visual

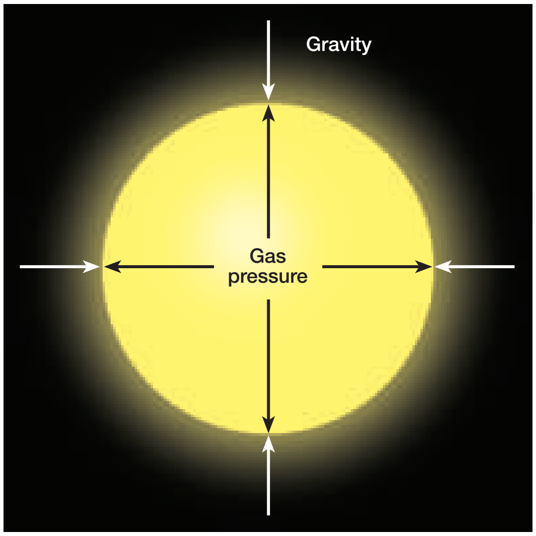


Figure 9 Balanced Forces A main-sequence star is balanced between gravity, which is trying to squeeze it, and gas pressure, which is trying to expand it.

Protostar Stage The initial contraction spans a million years or so. As time passes, the temperature of this gaseous body slowly rises until it is hot enough to radiate energy from its surface in the form of long-wavelength red light. This large red object is called a protostar. A **protostar** is a developing star not yet hot enough to engage in nuclear fusion.

During the protostar stage, gravitational contraction continues—slowly at first, then much more rapidly. This collapse causes the core of the protostar to heat much more intensely than the outer layer. **When the core of a protostar has reached about 10 million K, pressure within is so great that nuclear fusion of hydrogen begins, and a star is born.**

Heat from hydrogen fusion causes the gases to increase their motion. This in turn causes an increase in the outward gas pressure. At some point, this outward pressure exactly balances the inward force of gravity, as shown in Figure 9. When this balance is reached, the star becomes a stable main-sequence star. Stated another way, a stable main-sequence star is balanced between two forces: gravity, which is trying to squeeze it into a smaller sphere, and gas pressure, which is trying to expand it.

Main-Sequence Stage From this point in the evolution of a main-sequence star until its death, the internal gas pressure struggles to offset the unyielding force of gravity. Typically, hydrogen fusion continues for a few billion years and provides the outward pressure required to support the star from gravitational collapse.

Different stars age at different rates. Hot, massive blue stars radiate energy at such an enormous rate that they deplete their hydrogen fuel in only a few million years. By contrast, the least massive main-sequence stars may remain stable for hundreds of billions of years. A yellow star, such as the sun, remains a main-sequence star for about 10 billion years.

An average star spends 90 percent of its life as a hydrogen-burning, main-sequence star. Once the hydrogen fuel in the star's core is depleted, it evolves rapidly and dies. However, with the exception of the least-massive red stars, a star can delay its death by fusing heavier elements and becoming a giant.

Customize for Inclusion Students

Gifted Have students create a computer graphic presentation that compares the life cycles of different masses of stars. The presentations should include scale diagrams of each stage along with labels and a brief caption. Invite students to share their presentations with the class.

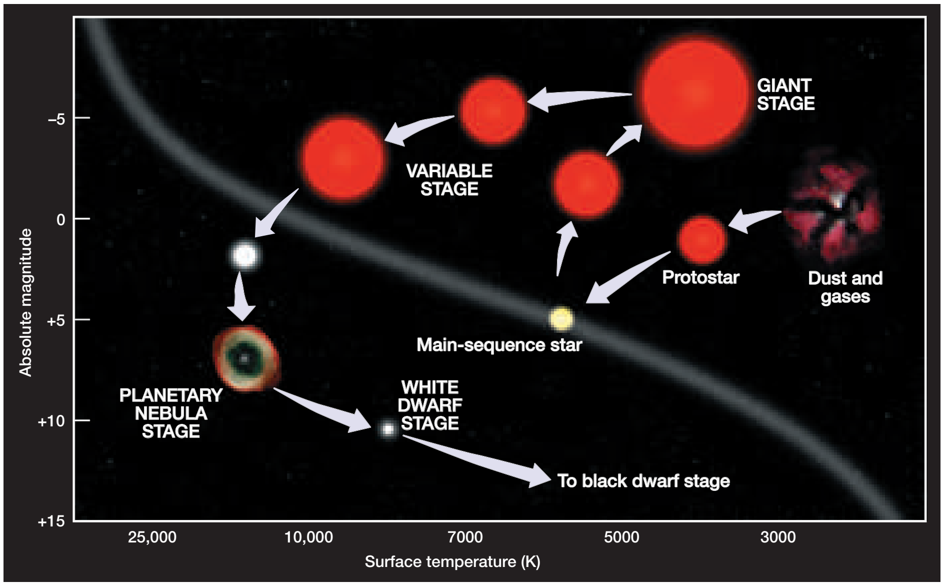


Figure 10 Life Cycle of a Sunlike Star A medium-mass star, similar to the sun, will evolve along the path shown here. **Interpreting Diagrams** ***What is the first stage in the formation of the star? What is the last stage?***

Red-Giant Stage The red-giant stage occurs because the zone of hydrogen fusion continually moves outward, leaving behind a helium core. Eventually, all the hydrogen in the star's core is consumed. While hydrogen fusion is still progressing in the star's outer shell, no fusion is taking place in the core. Without a source of energy, the core no longer has enough pressure to support itself against the inward force of gravity. As a result, the core begins to contract.

As the core contracts, it grows hotter by converting gravitational energy into heat energy. Some of this energy is radiated outward, increasing hydrogen fusion in the star's outer shell. This energy in turn heats and expands the star's outer layer. The result is a giant body hundreds to thousands of times its main-sequence size, as shown in Figure 10.

As the star expands, its surface cools, which explains the star's reddish appearance. During expansion, the core continues to collapse and heat until it reaches 100 million K. At this temperature, it is hot enough to convert helium to carbon. So, a red giant consumes both hydrogen and helium to produce energy.

Eventually, all the usable nuclear fuel in these giants will be consumed. The sun, for example, will spend less than a billion years as a giant. More massive stars will pass through this stage even more rapidly. The force of gravity will again control the star's destiny as it squeezes the star into the smallest, most dense piece of matter possible.

Reading Checkpoint *Why do red giants have a reddish appearance?*

Use Visuals L1

Figure 10 Use this figure to explain how a star like the sun evolves. Emphasize that the drawing shows changes in the characteristics of the star, not movement in the sky. Also explain that the main sequence is shown for reference. Ask: **What happens to the star after it leaves the main sequence?** *(It becomes a red giant.)* **How do the characteristics of the star change as it changes from a red giant to a planetary nebula?** (*It becomes hotter but less bright.)* **Where would the black dwarf stage be on the drawing? Why?** (*It would be in the bottom right corner or past it. A black dwarf is cold and dark.)*
Visual, Logical

Build Reading Literacy L1

Refer to **p. 446D** in **Chapter 16,** which provides guidelines for this sequence strategy.

Sequence Some students may be confused by the lifecycle of a sunlike star as pictured in Figure 10. To bypass the complexity of criteria such as surface temperature and absolute magnitude, have students write each step or phase on a separate flashcard. Then have them mix up the cards and practice placing them in the proper sequence.
Verbal, Kinesthetic

Answer to . . .

Figure 10 *The first stage is a nebula, or cloud of dust and gases. The last stage is a black dwarf.*

Reading Checkpoint *As they expand, their surfaces cool, which explains the red appearance.*

Burnout and Death

Use Visuals

L1

Figure 11 Use this figure to explain how the evolution of stars depends on their mass. Ask: **What stages do all stars go through?** *(nebula, protostar, main-sequence star)* **Which stars become red giants?** *(medium-mass and massive stars)* **Which stars become white dwarfs?** *(low-mass and medium-mass stars)* **What are two possible results of the death of a massive star?** *(It can become a neutron star or a black hole.)*
Visual, Logical

Address Misconceptions

L2

Students may be confused by the term *planetary nebula* and think that planets form from planetary nebulae. Explain that a planetary nebula is a stage in the evolution of a star and has nothing to do with planets. The name is a result of historical accident. When planetary nebulae were discovered 200 years ago, they looked like small greenish disks similar to the planet Uranus. Even though they are not related to planets, the name stuck.
Verbal

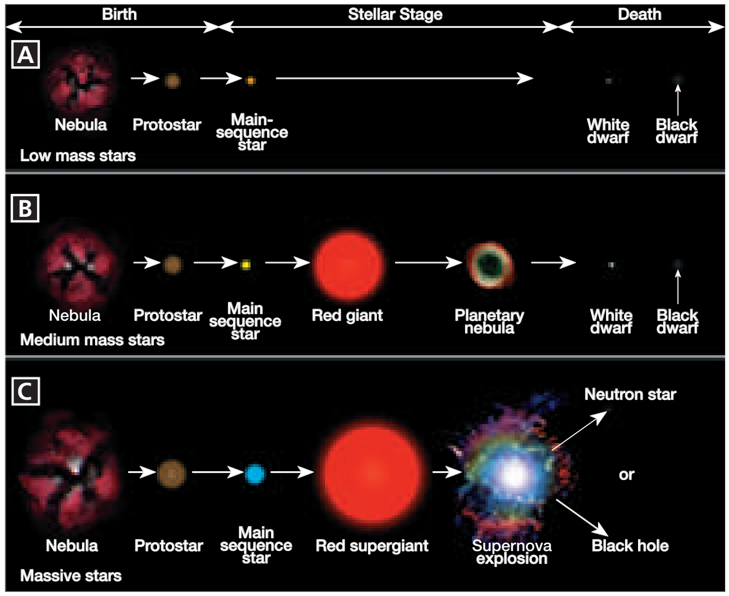


Figure 11 Stellar Evolution
A A low-mass star uses fuel at a low rate and has a long life span.
B Like a low-mass star, a medium-mass star ends as a black dwarf.
C Massive stars end in huge explosions, then become either neutron stars or black holes.

Burnout and Death

Most of the events of stellar evolution discussed so far are well documented. What happens next is based more on theory. **We do know that all stars, regardless of their size, eventually run out of fuel and collapse due to gravity.** With this in mind, let's consider the final stages of stars of different masses.

Death of Low-Mass Stars As shown in Figure 11A, stars less than one half the mass of the sun consume their fuel at a fairly slow rate. Consequently, these small, cool red stars may remain on the main sequence for up to 100 billion years. Because the interior of a low-mass star never reaches high enough temperatures and pressures to fuse helium, its only energy source is hydrogen. So, low-mass stars never evolve into red giants. Instead, they remain as stable main-sequence stars until they consume their hydrogen fuel and collapse into a white dwarf, which you will learn more about later.

Figure 12 Planetary Nebula
During its collapse from a red giant to a white dwarf, a medium-mass star ejects its outer layer, forming a round cloud of gas.

Death of Medium-Mass Stars As shown in Figure 11B, stars with masses similar to the sun evolve in essentially the same way. During their giant phase, sunlike stars fuse hydrogen and helium fuel at a fast rate. Once this fuel is exhausted, these stars also collapse into white dwarfs.

During their collapse from red giants to white dwarfs, medium-mass stars are thought to cast off their bloated outer layer, creating an expanding round cloud of gas. The remaining hot, central white dwarf heats the gas cloud, causing it to glow. These often beautiful, gleaming spherical clouds are called planetary nebulae. An example of a planetary nebula is shown in Figure 12.

Facts and Figures

In a few billion years, the sun's core will run out of hydrogen fuel, triggering hydrogen fusion in the surrounding shell. As a result, the sun's outer envelope will expand, producing a red giant hundreds of times larger and brighter. Intense solar radiation will boil Earth's oceans, and solar winds will drive away Earth's atmosphere. Another billion years later, the sun will expel its outermost layer, producing a planetary nebula. The interior will collapse to produce a small, dense white dwarf. Gradually the sun will emit its remaining energy and become a cold black dwarf.

710 Chapter 25

Death of Massive Stars

In contrast to sunlike stars, which die gracefully, stars with masses three times that of the sun have relatively short life spans, as shown in Figure 11C. These stars end their lives in a brilliant explosion called a **supernova.** During a supernova, a star becomes millions of times brighter than its prenova stage. If one of the nearest stars to Earth produced such an outburst, it would be brighter than the sun. Supernovae are rare. None have been observed in our galaxy since the invention of the telescope, although Tycho Brahe and Galileo each recorded one about 30 years apart. An even larger supernova was recorded in 1054 by the Chinese. Today, the remnant of this great outburst is the Crab Nebula, shown in Figure 13.

A supernova event is thought to be triggered when a massive star consumes most of its nuclear fuel. Without a heat engine to generate the gas pressure required to balance its immense gravitational field, the star collapses. This implosion, or bursting inward, is huge, resulting in a shock wave that moves out from the star's interior. This energetic shock wave destroys the star and blasts the outer shell into space, generating the supernova event.

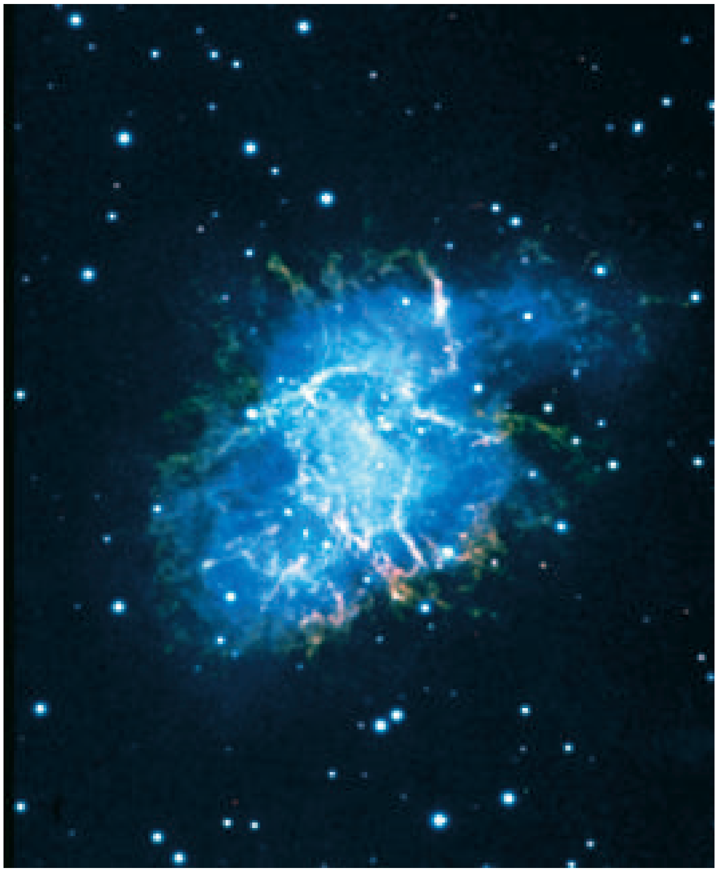


Figure 13 Crab Nebula This nebula, found in the constellation Taurus, is the remains of a supernova that took place in 1054.

H-R Diagrams and Stellar Evolution Hertzsprung-Russell diagrams have been helpful in formulating and testing models of stellar evolution. They are also useful for illustrating the changes that take place in an individual star during its life span. Refer back to Figure 10, which shows the evolution of a star about the size of the sun. Keep in mind that the star does not physically move along this path. Its position on the H-R diagram represents the color and absolute magnitude of the star at various stages in its evolution.

Reading Checkpoint *What is a supernova?*

Integrate Chemistry L2

Formation of Heavy Elements Tell students that all of the heavy (high atomic mass) atoms on Earth were formed inside stars. Initially the universe contained almost entirely hydrogen and helium. Biologically important elements such as carbon, nitrogen, and oxygen form inside many stars. However, very heavy elements such as lead and gold form only in the incredible explosions of supernovas. When the supernova fades, the elements are scattered throughout the area and may become part of a new solar system such as our own. Have students research the chain reactions inside stars and supernovas that produce heavy elements.
Logical

Use Community Resources L2

Invite an astronomer or astrophysicist from a local college or university to the classroom to discuss astronomy and research. Ask students to prepare questions in advance to ask the visitor.
Interpersonal

Answer to . . .

Reading Checkpoint *A supernova is the brilliant explosion that marks the end of a massive star.*

Stellar Remnants

Build Science Skills

L2

Using Analogies Use an analogy of a star to a charcoal briquette in a barbecue grill to describe the life of a low-mass star. When the briquette is first lit, it begins to consume its fuel and glows red-hot (main sequence). As it runs out of fuel, it becomes cooler and dimmer (white dwarf). Eventually it runs out of fuel and becomes a cold cinder (black dwarf). Ask students how the briquette is different from an actual star. *(The briquette burns because of chemical reactions, not fusion. It doesn't get hotter in the "white dwarf" stage.)* **Logical, Visual**

Stellar Remnants

Eventually, all stars consume their nuclear fuel and collapse into one of three documented states—white dwarf, neutron star, or black hole. Although different in some ways, these small, compact objects are all composed of incomprehensibly dense material and all have extreme surface gravity.

White Dwarfs **White dwarfs** are the remains of low-mass and medium-mass stars. They are extremely small stars with densities greater than any known material on Earth. Although some white dwarfs are no larger than Earth, the mass of such a dwarf can equal 1.4 times that of the sun. So, their densities may be a million times greater than water. A spoonful of such matter would weigh several tons. Densities this great are possible only when electrons are displaced inward from their regular orbits, around an atom's nucleus, allowing the atoms to take up less than the "normal" amount of space. Material in this state is called degenerate matter.

In degenerate matter, the atoms have been squeezed together so tightly that the electrons are displaced much nearer to the nucleus. Degenerate matter uses electrical repulsion instead of molecular motion to support itself from total collapse. Although atomic particles in degenerate matter are much closer together than in normal Earth matter, they still are not packed as tightly as possible. Stars made of matter that has an even greater density are thought to exist.

As a star contracts into a white dwarf, its surface becomes very hot, sometimes exceeding 25,000 K. Even so, without a source of energy, it can only become cooler and dimmer. Although none have been observed, the last stage of a white dwarf must be a small, cold body called a black dwarf. Table 2 summarizes the evolution of stars of various masses. **As you can see, the sun begins as a nebula, spends much of its life as a main-sequence star, becomes a red giant, planetary nebula, white dwarf, and finally, black dwarf.**

Table 2 Summary of Evolution for Stars of Various Masses

Initial Mass of Interstellar Cloud (Sun = 1)	Main-Sequence Stage	Giant Phase	Evolution After Giant Phase	Final Stage
1–3	Yellow	Yes	Planetary nebula	White dwarf
6	White	Yes	Supernova	Neutron star
20	Blue	Yes (Supergiant)	Supernova	Black hole

712 Chapter 25

Neutron Stars After studying white dwarfs, scientists made what might at first appear to be a surprising conclusion. The smallest white dwarfs are the most massive, and the largest are the least massive. The explanation for this is that a more massive star, because of its greater gravitational force, is able to squeeze itself into a smaller, more densely packed object than can a less massive star. So, the smaller white dwarfs were produced from the collapse of larger, more massive stars than were the larger white dwarfs.

This conclusion led to the prediction that stars smaller and more massive than white dwarfs must exist. These objects, called **neutron stars,** are thought to be the remnants of supernova events. In a white dwarf, the electrons are pushed close to the nucleus, while in a neutron star, the electrons are forced to combine with protons to produce neutrons. If Earth were to collapse to the density of a neutron star, it would have a diameter equal to the length of a football field. A pea-size sample of this matter would weigh 100 million tons. This is approximately the density of an atomic nucleus. Neutron stars can be thought of as large atomic nuclei.

Figure 14 Veil Nebula Located in the constellation Cygnus, this nebula is the remnant of an ancient supernova.

Supernovae During a supernova, the outer layer of the star is ejected, while the core collapses into a very hot neutron star about 20 kilometers in diameter. Although neutron stars have high surface temperatures, their small size would greatly limit their brightness. Finding one with a telescope would be extremely difficult.

However, astronomers think that a neutron star would have a very strong magnetic field. Further, as a star collapses, it will rotate faster, for the same reason ice skaters rotate faster as they pull in their arms. Radio waves generated by these rotating stars would be concentrated into two narrow zones that would align with the star's magnetic poles. Consequently, these stars would resemble a rapidly rotating beacon emitting strong radio waves. If Earth happened to be in the path of these beacons, the star would appear to blink on and off, or pulsate, as the waves swept past.

In the early 1970s, a source that radiates short bursts or pulses of radio energy, called a **pulsar**, was discovered in the Crab Nebula. Studies of this radio source revealed it to be a small spinning star centered in the nebula. The pulsar found in the Crab Nebula is undoubtedly the remains of the supernova of 1054.

Teacher Demo

Modeling a Pulsar

L2

Purpose Students observe a model of how a pulsar appears from Earth.

Materials string; long, thin flashlight

Procedure Tie a string to the middle of a long, thin flashlight. Twist the string a few times. Turn on the flashlight, turn off the room lights, and let the flashlight spin around. Ask: **What does the flashlight look like from your perspective?** *(It looks as if it is flashing on and off.)* **Is the flashlight actually flashing? If not, ask what it is doing.** *(No, it is producing a continuous beam.)* **Why does the flashlight appears to be flashing?** *(The beam is only visible when it points toward the observer.)* Twist the string more tightly and let the flashlight spin again. Ask: **What is different this time, and why?** *(The flashing is more frequent because the flashlight is rotating more rapidly.)*

Expected Outcome The flashlight will appear to be flashing and will appear to flash more rapidly as it rotates faster.
Visual, Logical

Facts and Figures

Pulsars were discovered by Jocelyn Bell Burnell in 1967. Burnell was a graduate student working on her advisor Anthony Hewish's project to study rapid fluctuations in radio waves received from stars. One day she noticed some strong, rapid, and regular pulses coming from fixed points on the sky. Some people thought the pulses might by signals sent by an alien civilization, or "little green men," so the sources were at first called LGM 1, LGM 2, LGM 3, and LGM 4. However, astronomers soon concluded that the signals had natural sources, which were named pulsars.

Section 25.2 (continued)

Use Visuals L1

Figure 15 Use this figure to explain how black holes can be detected. Ask: **Can a black hole be detected directly? Why or why not?** *(no, because its gravity is so strong that not even light can escape)* **What may happen if a black hole has a companion star?** *(The black hole may pull material out of the star and into itself.)* **What happens to material as it falls into a black hole?** *(It becomes very hot and emits X-rays.)* **What would be good evidence for a black hole?** *(stellar material being heated and then apparently disappearing into nothingness)*
Visual, Logical

3 ASSESS

Evaluate Understanding L2

Call on students to describe the stages that stars of different masses go through during their life cycles.

Reteach L1

Use Figure 10 to review the life cycle of a sunlike star and to emphasize that the H-R diagram is a graph, not a star chart.

Connecting Concepts

Sample answer: The effect on Earth would likely be devastating. Depending on the intensity of the radiation, living organisms would either be destroyed or genetically and physically damaged. Because the biosphere interacts with the remaining Earth systems, the entire Earth would be altered eventually.

Go Online NSTA SCI LINKS

Download a worksheet on black holes for students to complete, and find additional teacher support from NSTA SciLinks.

Black Holes Are neutron stars made of the most dense materials possible? No. During a supernova event, remnants of stars three times more massive than the sun apparently collapse into objects even smaller and denser than neutron stars. Even though these objects, called **black holes,** are very hot, their gravity is so strong that not even light can escape their surface. So they disappear from sight. Anything that moves too near a black hole would be swept in by its gravity and lost forever.

How can astronomers find an object whose gravitational field prevents the escape of all matter and energy? One strategy is to find evidence of matter being rapidly swept into a region of apparent nothingness. Scientists think that as matter is pulled into a black hole, it should become very hot and emit a flood of X-rays before being pulled in. Because isolated black holes would not have a source of matter to swallow up, astronomers first looked at binary-star systems.

A likely candidate for a black hole is Cygnus X-1, a strong X-ray source in the constellation Cygnus. In this case, the X-ray source can be observed orbiting a supergiant companion with a period of 5.6 days. It appears that gases are pulled from this companion and spiral into the disk-shaped structure around the black hole, as shown in Figure 15.

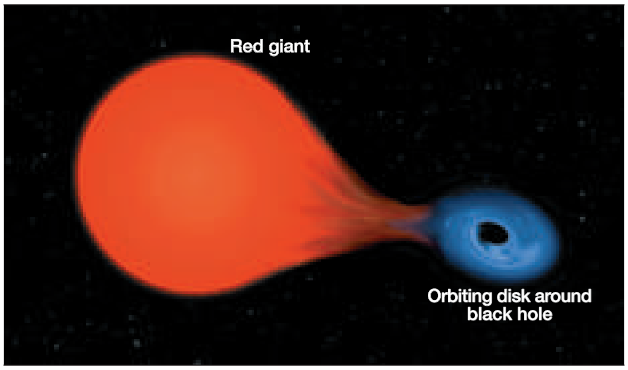


Figure 15 Black Hole Gases from the red giant spiral into the black hole.

Go Online SCI LINKS NSTA

For: Links on black holes
Visit: www.SciLinks.org
Web Code: cjn-7252

Section 25.2 Assessment

Reviewing Concepts

1. What is a protostar?
2. At what point is a star born?
3. What causes a star to die?
4. Describe the life cycle of the sun.

Critical Thinking

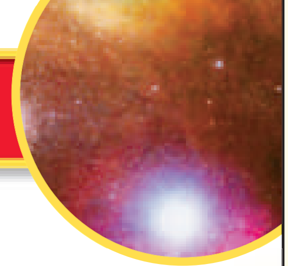
5. **Inferring** Why are less massive stars thought to age more slowly than more massive stars, even though less massive stars have much less "fuel"?
6. **Relating Cause and Effect** Why is interstellar matter important to stellar evolution?

Connecting Concepts

Supernova If a supernova explosion were to occur near our solar system, what might be some possible consequences of the intense X-ray radiation that would reach Earth?

Section 25.2 Assessment

1. A protostar is a developing star not yet hot enough to engage in nuclear fusion.
2. When the core of a protostar has reached about 10 million K, pressure within it is so great that nuclear fusion of hydrogen begins, and a star is born.
3. A star runs out of fuel and collapses due to gravity.
4. The sun began as a nebula, became a protostar and then a main-sequence star. It will become a red giant, planetary nebula, white dwarf, and finally a black dwarf.
5. A less massive star will live longer because it consumes fuel at a slower rate than do more massive stars.
6. Stars are born out of clouds of interstellar matter.



25.3 The Universe

Reading Focus

Key Concepts

- What is the size and structure of the Milky Way Galaxy?
- In what ways do galaxies differ from one another?
- What evidence indicates that the universe is expanding?
- According to the big bang theory, how did the universe begin?

Vocabulary

- galaxy
- galaxy cluster
- Hubble's law
- big bang theory

Reading Strategy

Outlining As you read, make an outline of the most important ideas in this section.

I. The Universe
  A. Milky Way Galaxy
    1. ____?____
    2. ____?____
  B. ____?____
    1. Spiral Galaxy
    2. Elliptical Galaxy
    3. ____?____

On a clear and moonless night away from city lights, you can see a truly marvelous sight—our own Milky Way Galaxy, as shown in Figure 16. **Galaxies** are groups of stars, dust, and gases held together by gravity. There may be more than 100 billion stars in the Milky Way Galaxy alone. Our galaxy looks milky because the solar system is located within a flat disk—the galactic disk. We view it from the inside and see stars in every direction.

The Milky Way Galaxy

When astronomers began to survey the stars located along the plane of the Milky Way, it appeared that equal numbers lay in every direction. Could Earth actually be at the center of the galaxy? Scientists came up with a better explanation. Imagine that the trees in an enormous forest represent the stars in the galaxy. After hiking into this forest, you look around. You see an equal number of trees in every direction. Are you in the center of the forest? Not necessarily. Anywhere in the forest will seem to be the center, except at the very edge.

Go Online SCILINKS NSTA

For: Links on galaxies
Visit: www.SciLinks.org
Web Code: cjn-7253

Figure 16 Milky Way Galaxy Notice the dark band caused by interstellar dark nebulae.

Section 25.3

1 FOCUS

Section Objectives

25.8 **Describe** the size and structure of the Milky Way Galaxy.
25.9 **List** the ways in which galaxies differ from one another.
25.10 **Cite** the evidence that indicates that the universe is expanding.
25.11 **Describe** how the universe began according to the big bang theory.

Reading Focus

Build Vocabulary L2

LINCS Have students use the LINCS strategy to learn and review the terms *galaxy*, *galactic cluster*, and *elliptical galaxy*. In LINCS exercises, students **L**ist what they know about each term, **I**magine a picture that describes the word, **N**ote a sound-alike word, **C**onnect the terms to the sound-alike word by making up a short story, and then perform a brief **S**elf-test.

Reading Strategy L2

A. Milky Way Galaxy
  1. Size—100,000 light-years wide and 10,000 light-years thick
  2. Structure—at least three spiral arms, nearly round halo
B. Types of Galaxies
  1. Spiral galaxy—disk-shaped, large
  2. Elliptical galaxy–round to oval, mostly small
  3. Irregular galaxy—Only 10 percent of galaxies have irregular shapes.
  4. Galactic clusters—groups of galaxies
C. Expanding Universe
  1. Red shifts—Light from distant galaxies is "stretched."
  2. Hubble's law—The universe is expanding.

Go Online NSTA SCILINKS

Download a worksheet on galaxies for students to complete, and find additional teacher support from NSTA SciLinks.

2 INSTRUCT

The Milky Way Galaxy

Build Science Skills L2

Inferring Tell groups of students to use a sharp pencil to carefully poke several dozen holes in a sheet of paper. Have them tape the sheets to a piece of cardboard and then look at them from the other side of the room. Ask students whether they can see the individual holes. *(no)* Ask students to compare the sheets to the photographs of the Milky Way on p. 715 and explain why both the Milky Way and the holes look fuzzy in both cases. *(The holes and stars are too small compared to their distances to be clearly visible.)*
Logical, Visual

Use Visuals L1

Figure 17 Use this figure to discuss the structure of the Milky Way Galaxy. Ask: **How wide is the Milky Way Galaxy?** *(about 100,000 light-years)* **What is at the center of the Milky Way Galaxy?** *(the nucleus)* **What part of the Milky Way Galaxy lies outside the main disk? What is it made up of?** *(the halo; thin gas and globular clusters)* **Where is the sun in the Milky Way Galaxy?** *(It is about two thirds of the way from the center on one of the spiral arms.)*
Visual, Logical

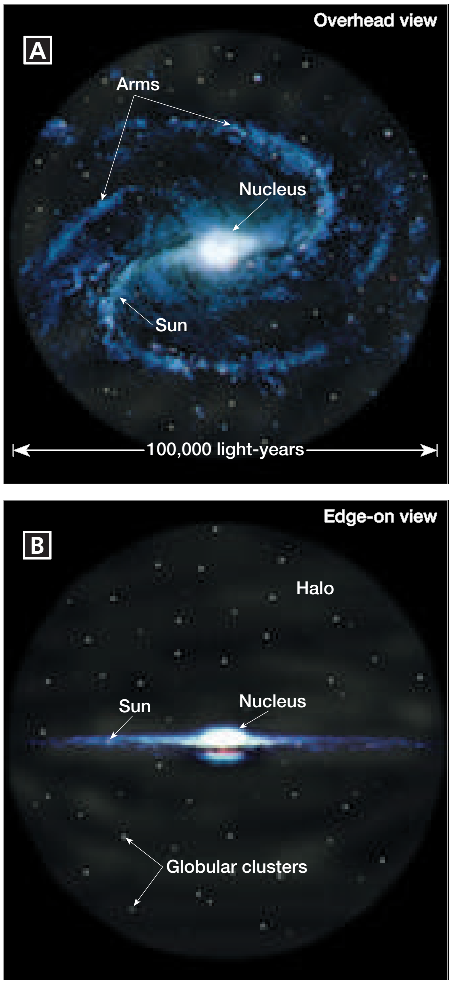


Figure 17 Structure of the Milky Way A The spiral arms are clearly visible in the overhead view of our galaxy. **B** Our solar system is located about 30,000 light-years from the galactic nucleus.

Size of the Milky Way It's hard to study the Milky Way Galaxy with optical telescopes because large quantities of interstellar matter block our vision. With the aid of radio telescopes, scientists have determined the structure of our galaxy. **The Milky Way is a large spiral galaxy whose disk is about 100,000 light-years wide and about 10,000 light-years thick at the nucleus, as shown in Figure 17A.** As viewed from Earth, the center of the galaxy lies beyond the constellation Sagittarius. Figure 17B shows an edge-on view of the Milky Way.

Reading Checkpoint *How big is the Milky Way Galaxy?*

Structure of the Milky Way Radio telescopes reveal that the Milky Way has at least three distinct spiral arms, with some signs of splintering. The sun is positioned in one of these arms about two thirds of the way from the center, or galactic nucleus, at a distance of about 30,000 light-years. The stars in the arms of the Milky Way rotate around the galactic nucleus. The most outward arms move the slowest, and the ends of the arms appear to trail. Our solar system orbits the galactic nucleus about every 200 million years.

Surrounding the galactic disk is a nearly round halo made of thin gas and numerous clusters of stars. These star clusters do not participate in the rotating motion of the arms but have their own orbits that carry them through the disk. Although some clusters are very dense, they pass among the stars of the arms with plenty of room to spare.

Reading Checkpoint *Where is our solar system located within the Milky Way Galaxy?*

Types of Galaxies

In the mid-1700s, German philosopher Immanuel Kant proposed that the fuzzy patches of light scattered among the stars were actually distant galaxies like the Milky Way. Today we know that the universe includes hundreds of billions of galaxies, each containing hundreds of billions of stars. From these hundreds of billions of galaxies, scientists have identified several basic types.

Customize for English Language Learners

Concepts such as galaxies, redshift, Hubble's law, and the big bang theory can be difficult to understand. Help English language learners understand these concepts by having them construct a Reading/Learning log. Have students write what they understand in the left column and what they still have questions about in the right column.

Spiral Galaxies As shown in Figure 18A, spiral galaxies are usually disk-shaped, with a somewhat greater concentration of stars near their centers. There are numerous variations, though. Viewed broadside, the arms are often seen extending from the central nucleus and sweeping gracefully away. The outermost stars of these arms rotate most slowly, giving the galaxy the appearance of a pinwheel.

One type of spiral galaxy, however, has its stars arranged in the shape of a bar, which rotates as a rigid system. Attached to each end of these bars are curved spiral arms. These have become known as barred spiral galaxies, as shown in Figure 18B. Recent evidence indicates that the Milky Way may be a barred spiral galaxy. Spiral galaxies are generally quite large. About 10 percent of all galaxies are thought to be barred spirals, and another 20 percent are regular spiral galaxies.

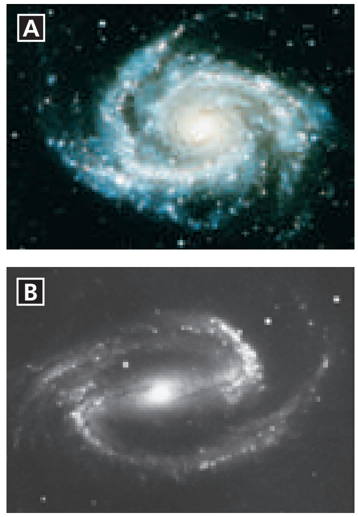


Figure 18 Spiral Galaxies
A A spiral galaxy looks somewhat like a pinwheel. **B** A barred spiral galaxy has a bar through its center, with arms extending outward from the bar.

Elliptical Galaxies About 60 percent of galaxies are classified as elliptical galaxies. Elliptical galaxies range in shape from round to oval. Although most are small, the very largest known galaxies—200,000 light-years in diameter—are elliptical. This type of galaxy, shown in Figure 19, does not have spiral arms.

Irregular Galaxies Only 10 percent of the known galaxies have irregular shapes and are classified as irregular galaxies. The best-known irregular galaxies, the Large and Small Magellanic Clouds, are easily visible with the unaided eye. These galaxies were named after the explorer Ferdinand Magellan, who observed them when he sailed around Earth in 1520. They are our nearest galactic neighbors—only 150,000 light-years away. An irregular galaxy is shown in Figure 20.

In addition to shape and size, one of the major differences among different types of galaxies is the age of their stars. Irregular galaxies are composed mostly of young stars, while elliptical galaxies contain old stars. The Milky Way and other spiral galaxies have both young and old stars, with the youngest located in the arms.

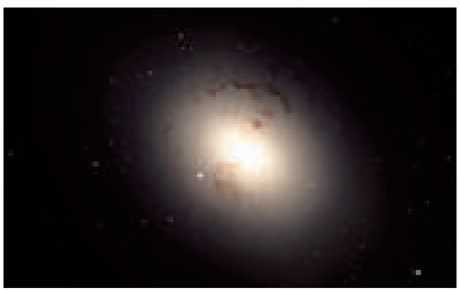


Figure 19 Elliptical Galaxy Most galaxies are classified as elliptical with shapes ranging from round to oval.

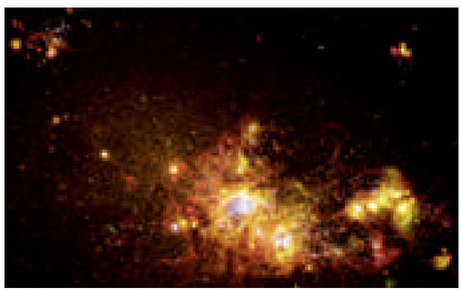


Figure 20 Irregular Galaxy Irregular galaxies have irregular shapes.
Describing ***What type of stars would you find in an irregular galaxy?***

Types of Galaxies

Build Science Skills L2

ACTIVITY

Using Models Invite students to make models of different types of galaxies, using cotton balls, coat hangers, and other materials of their choice. Each student should model at least two different types of galaxies. Students should write paragraphs on index cards explaining each galaxy and its characteristics. Have students calculate and include the approximate scale of their models. Have students view some of the models of spiral galaxies from the side and close up so they see why it is so hard for us to see the structure of our own galaxy.
Logical, Visual

Use Visuals L1

Figures 18–20 Use these figures to compare and contrast the different types of galaxies. Ask: **How is a spiral galaxy different from an elliptical galaxy?** *(A spiral galaxy has arms; an elliptical galaxy doesn't.)* **How is an irregular galaxy different from other galaxies?** *(An irregular galaxy does not have a regular shape.)* **How are all galaxies similar?** *(They are all made up of stars and have a denser region at their center.)*
Visual, Logical

Answer to . . .

Figure 20 *Irregular galaxies are composed mostly of young stars.*

Reading Checkpoint *The Milky Way Galaxy is about 100,000 light-years wide and 10,000 light-years thick at the nucleus.*

Reading Checkpoint *Our solar system is about two thirds of the way from the center on one of the spiral arms of the galaxy.*

Beyond Our Solar System 717

The Expanding Universe

Integrate Physics

L2

Doppler Effect Review the electromagnetic spectrum and the Doppler effect. Ask: **What is the electromagnetic spectrum?** *(the full range of frequencies of electromagnetic radiation)* **What is visible light?** *(the part of the spectrum that the human eye can see)* **What is wavelength?** *(the distance from the peak of one wave to the peak of the next)* **How does the Doppler effect affect wavelength if the source of the waves is moving toward the observer?** *(The waves will seem to be closer together. They will have a smaller wavelength.)* **Logical**

Teacher Demo

"Stretching" Light Waves

L2

Purpose Students observe a model of how light is redshifted.

Materials old bicycle inner tube, scissors, chalk

Procedure Before the demo, cut an old bicycle inner tube on both sides of the valve to form a long tube. Cut the tube lengthwise to form a long narrow band of rubber. In front of the students, use white chalk to draw a galaxy at one end of the tube to represent the Milky Way. Draw another galaxy at the other end. Draw a wavy line to represent light coming from the other galaxy toward the Milky Way. Then, hold both ends of the strip and stretch them apart. Ask students what happens to the "wave." *(It gets stretched out.)* Ask how this affects the color of the light. *(The wavelength increases, so the light is shifted toward the red end of the spectrum.)* Tell students that light from distant galaxies is redshifted by a similar process.

Expected Outcome Students will observe the "wave" being "redshifted." **Visual, Logical**

Figure 21 Galaxy Cluster This cluster of galaxies is located about 1 million light-years from Earth.

Galaxy Clusters Once astronomers discovered that stars were found in groups, they wondered whether galaxies also were grouped or just randomly distributed throughout the universe. They found that, like stars, galaxies are grouped in **clusters.** One such cluster is shown in Figure 21. Some clusters may contain thousands of galaxies. Our own cluster, called the Local Group, contains at least 28 galaxies. Of these, three are spirals, 11 are irregulars, and 14 are ellipticals. Galaxy clusters also make up huge groups called superclusters. Studies indicate that superclusters may be the largest entities in the universe.

Reading Checkpoint *Describe the shape of elliptical galaxies.*

The Expanding Universe

Recall the Doppler effect that you read about in Chapter 24. Remember that when a source is moving away, its light appears redder than it actually is, because its waves appear lengthened. Objects approaching have their light waves shifted toward the blue or shorter wavelengths. Therefore, the Doppler effect reveals whether a star or other body in space is moving away from Earth or toward Earth. The amount of shift allows us to calculate the rate at which the relative movement is occurring. Large Doppler shifts indicate higher speeds; smaller Doppler shifts indicate lower speeds.

Red Shifts One of the most important discoveries of modern astronomy was made in 1929 by Edwin Hubble. Observations completed several years earlier revealed that most galaxies have Doppler shifts toward the red end of the spectrum. The red shift occurs because the light waves are "stretched," which shows that Earth and the source are moving away from each other. Hubble set out to explain this red shift phenomenon.

Hubble realized that dimmer galaxies were probably farther away than were brighter galaxies. He tried to determine whether a relationship existed between the distances to galaxies and their red shifts. Hubble used estimated distances based on relative brightness and Doppler red shifts to discover that galaxies that exhibit the greatest red shifts are the most distant.

Reading Checkpoint *What relationship did Hubble discover between red shifts and the distances of galaxies from Earth?*

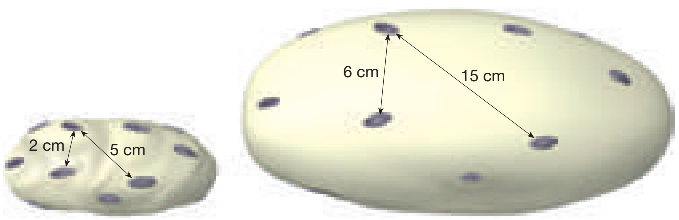
Hubble's Law A consequence of the universal red shift is that it predicts that most galaxies—except for a few nearby—are moving away from us. Recall that the amount of Doppler red shift depends on the speed at which the object is moving away. Greater red shifts indicate faster speeds. Because more distant galaxies have greater red shifts, Hubble concluded that they must be retreating from us at greater speeds. This idea is currently termed **Hubble's law.** It states that galaxies are retreating from us at a speed that is proportional to their distance.

Hubble was surprised at this discovery because it implied that the most distant galaxies are moving away from us many times faster than those nearby. What does this mean? **The red shifts of distant galaxies indicate that the universe is expanding.**

To help visualize the nature of this expanding universe, imagine a loaf of raisin bread dough that has been set out to rise for a few hours. As shown in Figure 22 , as the dough doubles in size, so does the distance between all of the raisins. However, the raisins that were originally farther apart traveled a greater distance in the same time span than those located closer together. We therefore conclude that in an expanding universe, as in the raisin bread dough analogy, those objects located farther apart move away from each other more rapidly.

Another feature of the expanding universe can be demonstrated. No matter which raisin you select, it will move away from all the other raisins. Likewise, no matter where one is located in the universe, every other galaxy—again, except those in the same cluster—will be moving away. Hubble had indeed advanced our understanding of the universe. The Hubble Space Telescope is named in his honor.

Reading Checkpoint *What is Hubble's law?*



Raisin bread dough before it rises.

Raisin bread dough a few hours later.

A

B

Figure 22 Raisin Dough Analogy As the dough rises, raisins that were farther apart travel a greater distance in the same time as those that were closer together. Like galaxies in an expanding universe, the distant raisins move away from one another more rapidly than those that are near one another.

Use Visuals L1

Figure 22 Use this figure to explain how the universe is expanding. Tell students to imagine that the galaxy at the top left is our galaxy. Ask: **If the raisin that is 2 cm from us becomes 6 cm away 2 hours later, how fast is it moving relative to us?** *([6 cm − 2 cm] / 2 hr = 2 cm/hr)* **If the raisin that is 5 cm from us becomes 15 cm away 2 hours later, how fast is it moving relative to us?** *([15 cm − 5 cm] / 2 hr = 5 cm/hr)* **How do your answers relate to Hubble's law?** *(The farther away a galaxy is, the faster it is moving.)*
Visual, Logical

Build Science Skills L2

ACTIVITY

Use Analogies The text cites the raisin dough analogy as a way of explaining the expansion of the universe. Model a Slinky as an analogy for red shifts. Have groups of two grip each side of a Slinky. Instruct one student to stay in place, and another to slowly back away. Ask students to discuss the following: **Which of you represents our galaxy?** *(the stationary student)* **Which of you represents a galaxy that is moving away?** *(the student who is backing up)* **How does the Slinky represent a red shift?** *(As the coils stretch, the distance between each one grows, modeling the lengthening of wavelengths over distance.)*
Kinesthetic, Interpersonal

Facts and Figures

Edwin Hubble was born in 1889 in Marshfield, Missouri. He initially studied law and only later decided to go into astronomy. In the early 1920s, astronomers did not know whether some "spiral nebulae" were small clouds of stars within our galaxy or separate galaxies entirely. Hubble measured the distance to the Andromeda nebula in 1924 and showed that it was about 100,000 times as far away as nearby stars. He concluded that it was a separate galaxy. In 1929, Hubble established that the red shift of galaxies was proportional to their distance, and thus that the universe is expanding. Much of Hubble's work was done using what at the time was the world's best telescope—the 100-in. telescope on Mt. Wilson in California. Hubble died in 1953.

Answer to . . .

Reading Checkpoint *Elliptical galaxies range in shape from round to oval.*

Reading Checkpoint *Galaxies that have the greatest red shifts are the most distant.*

Reading Checkpoint *Hubble's law states that galaxies are receding from Earth at a speed that is proportional to their distance.*

The Big Bang
Build Reading Literacy
L1

Refer to **p. 698D,** which provides guidelines for sequencing.

Sequence While reading about the big bang, have students create a flowchart showing the chain of events starting with the big bang and ending with the formation of stars and galaxies. *(big bang → atoms form → gases cool and condense → stars and galaxies form)*
Visual, Verbal

Address Misconceptions
L2

Students may think that the big bang occurred at a certain point at the center of the universe. They may also think that material from the big bang exploded into already existing space. Tell students that space itself expanded as a result of the big bang. Space is within the universe rather than the universe being within space. There is no center from which the universe is expanding. The big bang essentially occurred everywhere at once. Evidence for this is that the cosmic background radiation comes from every direction, not just from a specific location.
Verbal

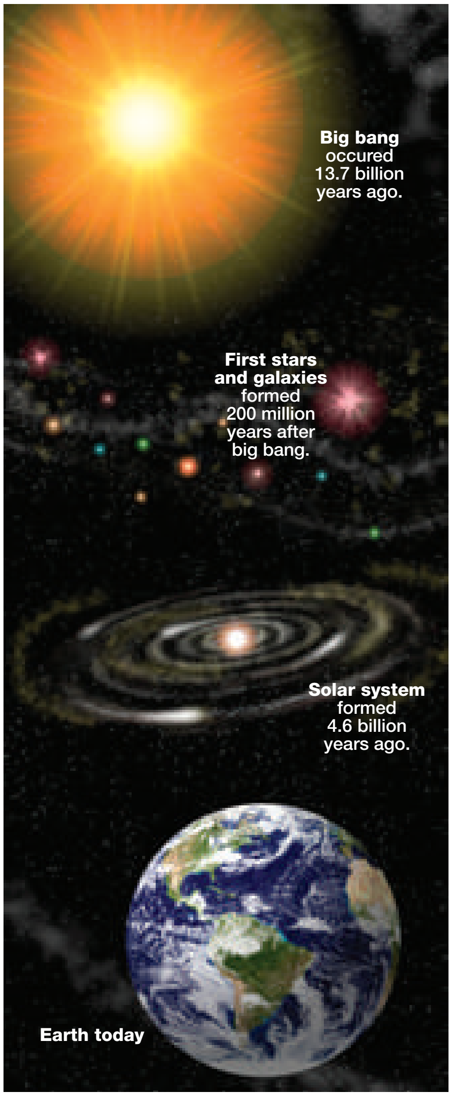


Figure 23 The Big Bang
According to the big bang theory, the universe began 13.7 billion years ago. Two hundred million years later, the first stars and galaxies began to form.

The Big Bang

Did the universe have a beginning? Will it have an end? Scientists are trying to answer these questions.

Any theory about the origin of the universe must account for the fact that all distant galaxies are moving away from us. Because all galaxies appear to be moving away from Earth, is our planet in the center of the universe? Probably not, because if we are not even in the center of our own solar system, and our solar system is not even in the center of the galaxy, it seems unlikely that we could be in the center of the universe.

A more probable explanation exists. Imagine a balloon with paper-punch dots glued to its surface. When the balloon is inflated, each dot spreads apart from every other dot. Similarly, if the universe is expanding, every galaxy would be moving away from every other galaxy.

This concept of an expanding universe led to the widely accepted big bang theory. According to the **big bang theory,** the universe began as a violent explosion from which the universe continues to expand, evolve, and cool. **The big bang theory states that at one time, the entire universe was confined to a dense, hot, supermassive ball. Then, about 13.7 billion years ago, a violent explosion occurred, hurling this material in all directions.** The big bang, as shown in Figure 23, marks the beginning of the universe. All matter and space were created at that instant. After several hundred thousand years, the universe became cool enough for atoms to form. Gases in the universe continued to cool and condense. They eventually formed the stars that make up the galaxies we now observe moving away from us.

Supporting Evidence Through decades of experimentation and observation, scientists have gathered substantial evidence that supports the big bang theory. For example, the red shift of galaxies that you read about earlier indicates that the universe is still expanding. Scientists discovered a type of energy called cosmic background radiation. This energy was detected as faint radio signals coming from every direction in space. Scientists think that this radiation was produced during the big bang.

Reading Checkpoint *What evidence supports the big bang?*

The Big Crunch? If the universe began with a big bang, how will it end? One view is that the universe will last forever. In this scenario, the stars will slowly burn out, being replaced by invisible degenerate matter and black holes that will travel outward through an endless, dark, cold universe. The other possibility is that the outward flight of the galaxies will slow and eventually stop. Gravitational contraction would follow, causing the galaxies to collide and combine into the high-energy, high-density mass from which the universe began. This fiery death of the universe, the big bang operating in reverse, has been called the "big crunch."

Whether or not the universe will expand forever or eventually collapse upon itself depends on its average density. If the average density of the universe is more than its critical density—about one atom for every cubic meter—the gravitational field is enough to stop the outward expansion and cause the universe to contract. On the other hand, if the density of the universe is less than the critical value, it will expand forever. Current estimates of the density of the universe place it below the critical density, which predicts an ever-expanding, or open, universe. Additional support for an open universe comes from studies that indicate the universe is expanding faster now than in the past. The view currently favored by most scientists is an expanding universe with no ending point.

It should be noted, however, that the methods used to determine the ultimate fate of the universe have substantial uncertainties. It is possible that previously undetected matter exists in great quantities in the universe. If this is so, the galaxies could, in fact, collapse in the "big crunch."

Section 25.3 Assessment

Reviewing Concepts

1. What is a galaxy?
2. Describe the size and structure of the Milky Way Galaxy.
3. How do galaxies differ?
4. What evidence indicates that the universe is expanding?
5. What is the big bang theory?

Critical Thinking

6. **Comparing and Contrasting** Compare and contrast the three types of galaxies.
7. **Inferring** If the universe is an open universe, what can you infer about its average density?

Writing in Science

Descriptive Paragraph Scientists are continuously searching the Milky Way Galaxy for other stars that may have planets. What types of stars would most likely have a planet or planets suitable for life as we know it? Write a paragraph describing these stars.

3 ASSESS

Evaluate Understanding L2

Write "The Expanding Universe" on the board. Ask students to contribute ideas that indicate that the universe is expanding.

Reteach L1

Have students use Figures 18–20 to review the basic types of galaxies.

Writing in Science

Medium-mass stars, like our sun, may be the most likely candidates to have planets that support life. In our own galaxy, there are millions of sun-like stars. If these stars are orbited by planets, the existence of life would depend on the planets' composition and temperature, among other factors.

Answer to . . .

Reading Checkpoint *The red shift of distant galaxies and cosmic background radiation support the big bang.*

Section 25.3 Assessment

1. A galaxy is a group of stars, dust, and gases held together by gravity.
2. The Milky Way is a large spiral galaxy whose disk is about 100,000 light-years wide and about 10,000 light-years thick at the nucleus.
3. Galaxies differ in size, shape, and the ages of their stars.
4. The red shifts of distant galaxies indicate that the universe is expanding.
5. The big bang theory states that about 13.7 billion years ago, the universe began at one point and has been expanding at close to the speed of light ever since.
6. The most obvious difference is their shape: spiral galaxies have arms; elliptical galaxies range in shape from round to oval; irregular galaxies have no regular shape. Irregular galaxies are composed mostly of young stars, while elliptical galaxies contain mostly older stars. Spiral galaxies are composed of stars of various ages, with the youngest stars in the arms.
7. Its average density must be less than its critical density.

Astrology—Forerunner of Astronomy L2

Background
Until about 400 years ago, science was not a separate field of study as it is today. It was rare for anyone to study the natural world merely out of curiosity. Belief in what we would now call unscientific superstitions was quite common even among well-educated people. Kepler, for example, believed that observations of the stars could be used to predict future events. Part of his job as an astronomy professor was to make such predictions.

Teaching Tips
- Have students make a table with the headings Astronomy and Astrology. As student read the feature, have them note the features of each. When they are finished, have them use their tables to make a Venn diagram showing the differences and similarities between astronomy and astrology.
- Have students research early astronomers and the connections between astronomy and the rest of society at that time. Ask them to present a brief report to the class.

Visual, Logical

understanding EARTH: Astrology—Forerunner of Astronomy

Many people confuse astrology and astronomy to the point of believing these terms to be synonymous. Nothing can be further from the truth. Astronomy is a scientific investigation of the universe to discover the properties of celestial objects and the laws under which the universe operates. Astrology, on the other hand, is based on ancient superstitions that a person's actions and personality are based on the positions of the planets and stars now, and at the person's birth. Scientists do not accept astrology, regarding it as a pseudoscience ("false science"). Most people who read horoscopes do so only as a pastime and do not let them influence their daily living.

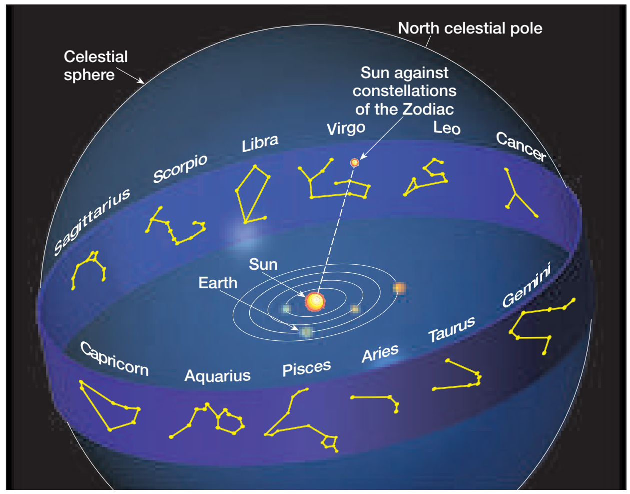


Figure 24 The Constellations of the Zodiac Earth is shown in its autumn (September) position in orbit, from which the sun is seen against the background of the constellation Virgo.

Astrology began more than 3000 years ago when the positions of the planets were plotted as they regularly migrated against the background of the "fixed" stars. Because the solar system is "flat," like a whirling Frisbee, the planets orbit the sun along nearly the same plane. Therefore, the planets, sun, and moon all appear to move along a band around the sky known as the zodiac. Because Earth's moon cycles through its phases about 12 times each year, the Babylonians divided the zodiac into 12 constellations, as shown in Figure 24. Thus, each successive full moon can be seen against the backdrop of the next constellation.

When the zodiac was first established, the vernal equinox (first day of spring) occurred when the sun was viewed against the constellation Aries. However, during each succeeding vernal equinox, the position of the sun shifts very slightly against the background of stars. Now, over 2000 years later, the vernal equinox occurs when the sun is in Pisces. In several years, the vernal equinox will occur when the sun appears against Aquarius.

Although astrology is not a science and has no basis in fact, it did contribute to the science of astronomy. The positions of the moon, sun, and planets at the time of a person's birth (sign of the zodiac) were considered to have great influence on that person's life. Even the great astronomer Kepler was required to make horoscopes part of his duties. To make horoscopes for the future, astrologers tried to predict the future positions of the celestial bodies. Thus, some of the improvements in astronomical instruments were made because of the desire for more accurate predictions of events such as eclipses, which were considered highly significant in a person's life.

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