Section 1

The Air Around You

Reading Preview

Key Concepts

- What is the composition of Earth's atmosphere?
- How is the atmosphere important to living things?
- What causes smog and acid rain?

Key Terms

- weather
- atmosphere
- ozone
- water vapor
- pollutant
- photochemical smog
- acid rain

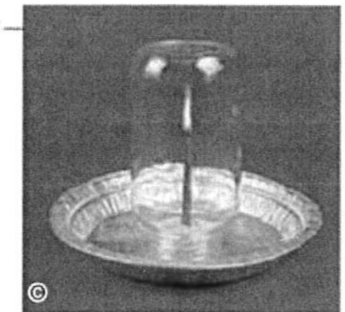
Target Reading Skill

Using Prior Knowledge Before you read, look at the section headings and visuals to see what this section is about. Then write what you know about the atmosphere in a graphic organizer like the one below. As you read, write what you learn.

What You Know
1. The atmosphere contains oxygen. 2.

What You Learned
1. 2.

Lab zone Standards Warm-Up



How Long Will the Candle Burn?

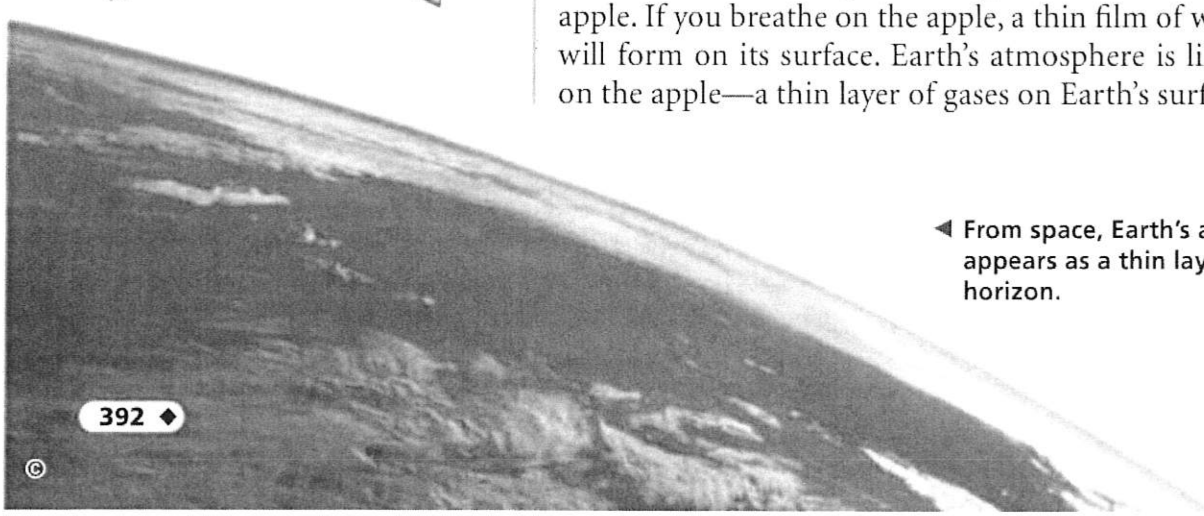
1. Put on your goggles.
2. Stick a small piece of modeling clay onto an aluminum pie pan. Push a short candle into the clay. Carefully light the candle.
3. Hold a small glass jar by the bottom. Lower the mouth of the jar over the candle until the jar rests on the pie pan. As you do this, start a stopwatch or note where the second hand is on a clock.
4. Watch the candle carefully. How long does the flame burn?
5. Wearing an oven mitt, remove the jar. Relight the candle and then repeat Steps 3 and 4 with a larger jar.

Think It Over

Inferring How would you explain any differences between your results in Steps 4 and 5?

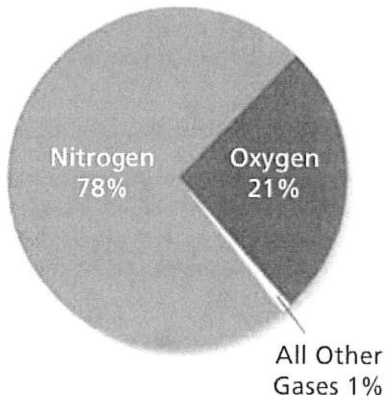
The sky is full of thick, dark clouds. In the distance you see a bright flash. Thirty seconds later, you hear a crack of thunder. You begin to run and reach your home just as the downpour begins. That was close! From your window you look out to watch the storm.

Does the weather where you live change often, or is it fairly constant from day to day? **Weather** is the condition of Earth's atmosphere at a particular time and place. But what is the atmosphere? Earth's **atmosphere** (AT muh sfeer) is the envelope of gases that surrounds the planet. To understand the relative size of the atmosphere, imagine that Earth is the size of an apple. If you breathe on the apple, a thin film of water droplets will form on its surface. Earth's atmosphere is like that water on the apple—a thin layer of gases on Earth's surface.



◀ From space, Earth's atmosphere appears as a thin layer near the horizon.

Gases in Dry Air



Other Gases	Percentage by Volume
Argon	0.93
Carbon dioxide	0.038
Neon	0.0018
Helium	0.00052
Methane	0.00015
Krypton	0.00011
Hydrogen	0.00005

FIGURE 1
Dry air in the lower atmosphere generally has about the same composition of gases.
Interpreting Data
What two gases make up most of the air?

Composition of the Atmosphere

The atmosphere is made up of a mixture of atoms and molecules of different kinds. An atom is the smallest unit of a chemical element that can exist by itself. Molecules are made up of two or more atoms. **Earth's atmosphere is made up of nitrogen, oxygen, carbon dioxide, water vapor, and many other gases, as well as particles of liquids and solids.**

Nitrogen As you can see in Figure 1, nitrogen is the most common gas in the atmosphere. It makes up a little more than three fourths of the air we breathe. Each nitrogen molecule consists of two nitrogen atoms. Nitrogen moves in a cycle from the air to the soil, into living things, and then back into the air.

Oxygen Even though oxygen is the second most abundant gas in the atmosphere, it makes up less than one fourth of the volume. Plants and other organisms use light to convert water and carbon dioxide into oxygen and to produce food. Thus, like nitrogen, the oxygen in the air moves through a natural cycle involving living things.

Oxygen is also involved in many other important processes. Any fuel you can think of, from the gasoline in a car to the candles on a birthday cake, uses oxygen as it burns. Without oxygen, a fire will go out. Burning uses oxygen rapidly. During other processes, oxygen is used slowly. For example, steel reacts slowly with oxygen to form iron oxide, or rust.

Most oxygen molecules have two oxygen atoms. Ozone is a form of oxygen that has three oxygen atoms in each molecule instead of the usual two.

Reading Checkpoint What is ozone?

FIGURE 2
Burning Uses Oxygen
Oxygen is necessary in order for the wood to burn.

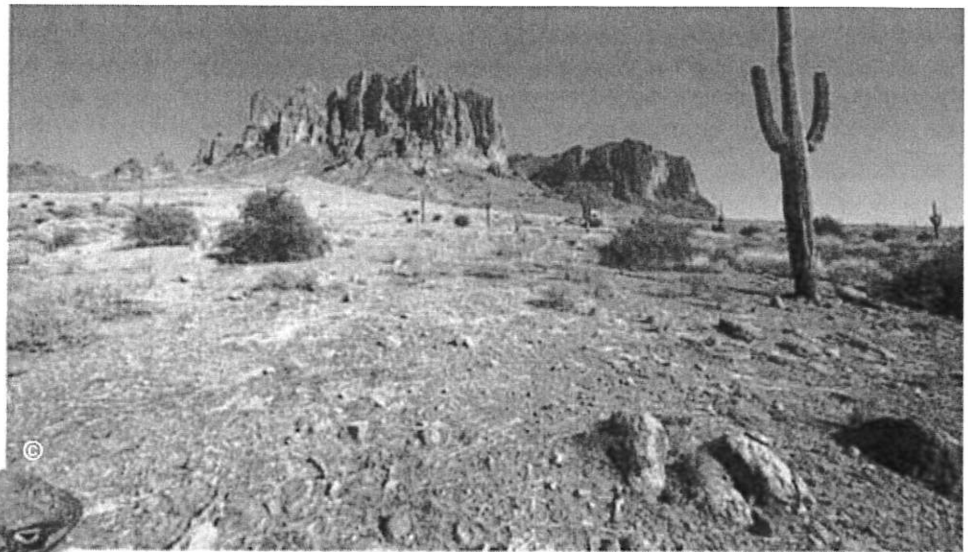


FIGURE 3
Water Vapor in the Air
There is very little water vapor in the air over the desert where this lizard lives. In the tropical rain forest (right), where the frog lives, as much as four percent of the air may be water vapor.

Carbon Dioxide Each molecule of carbon dioxide has one atom of carbon and two atoms of oxygen. Carbon dioxide is essential to life. Plants take in carbon dioxide from the air to make food. When plant and animal cells break down food to produce energy, they give off carbon dioxide as a waste product.

When fuels such as coal and gasoline are burned, they release carbon dioxide. Burning these fuels increases the amount of carbon dioxide in the atmosphere.

Other Gases Oxygen and nitrogen together make up 99 percent of dry air. Argon and carbon dioxide make up most of the other one percent. The remaining gases are called trace gases because only small amounts of them are present.

Water Vapor So far, we have discussed the composition of dry air. In reality, air is not dry because it contains water vapor. **Water vapor** is water in the form of a gas. Water vapor is invisible. It is not the same thing as steam, which is made up of tiny droplets of liquid water. Each water molecule contains two atoms of hydrogen and one atom of oxygen.

The amount of water vapor in the air varies greatly from place to place and from time to time. Water vapor plays an important role in Earth's weather. Clouds form when water vapor condenses out of the air to form tiny droplets of liquid water or crystals of ice. If these droplets or crystals become heavy enough, they can fall as rain or snow.

Particles Pure air contains only gases. But pure air exists only in laboratories. The air we breathe also contains tiny solid and liquid particles of dust, smoke, salt, and other chemicals. You can see some of these particles in the air around you, but most of them are too small to see.

Reading Checkpoint **What is water vapor?**

Lab zone **Try This Activity**

Breathe In, Breathe Out

How can you detect carbon dioxide in the air you exhale?

1. Put on your goggles.
2. Fill a glass or beaker halfway with limewater.
3. Using a straw, slowly blow air through the limewater for about a minute. **CAUTION:** *Do not suck on the straw or drink the limewater.*
4. What happens to the limewater?

Developing Hypotheses
What do you think would happen if you did the same experiment after jogging for 10 minutes? What would your results tell you about exercise and carbon dioxide?

Importance of the Atmosphere

Earth's atmosphere makes conditions on Earth suitable for living things. The atmosphere contains oxygen and other gases that living things need to survive. Living things also need warmth and liquid water. By trapping energy from the sun, the atmosphere keeps most of Earth's surface warm enough for water to exist as a liquid. In addition, Earth's atmosphere protects living things from ultraviolet radiation from the sun. The atmosphere also prevents Earth's surface from being hit by most meteoroids, which are rocks from outer space.

The atmosphere is constantly changing, with gases such as nitrogen, oxygen, and carbon dioxide moving in and out of living things, the land, and the water. From this point of view, air can be considered a renewable resource.

Go Online
SCILINKS NSTA

For: Links on the atmosphere
Visit: www.SciLinks.org
Web Code: scn-0911

Air Quality

Breathing brings air into your lungs, where the oxygen you need is taken into your body. But not everything in the air is healthful. You may also breathe in tiny particles or even a small amount of harmful gases.

If you live in a large city, you may have noticed a brown haze in the air. Even if you live far from a city, the air around you may contain pollutants. **Pollutants** are harmful substances in the air, water, or soil. Air that contains harmful particles and gases is said to be polluted. Air pollution can affect the health of humans and other living things.

Sources of Pollution Some pollution occurs naturally. For example, many natural processes add particles to the atmosphere. Forest fires, soil erosion, and dust storms release a great deal of smoke and dust into the air. The wind carries particles of molds and pollen. Erupting volcanoes spew out clouds of dust and ash along with poisonous gases.

Go Online
PHSchool.com

For: More on air pollution
Visit: PHSchool.com
Web Code: cfd-4014

Most air pollution is the result of burning fossil fuels, such as coal, oil, gasoline, and diesel fuel. Almost half of this pollution comes from cars and other motor vehicles. Factories and power plants that burn coal and oil also release pollution. Burning fossil fuels produces a variety of pollutants, including carbon monoxide, nitrogen oxides, and sulfur oxides.

Smog and Acid Rain High levels of air pollution decrease the quality of the air. **The burning of fossil fuels can cause smog and acid rain.** One hundred years ago, the city of London, England, was dark and dirty. Factories burned coal, and most houses were heated by coal. The air was full of soot. In 1905, the term *smog* was created by combining the words *smoke* and *fog* to describe this type of air pollution.

Fortunately, London-type smog is no longer common. Instead, many cities today have another type of smog. The brown haze that develops in sunny cities is called **photochemical smog** (foh toh KEM ih kul). The *photo-* in photochemical means "light." Photochemical smog is formed by the action of sunlight on pollutants such as hydrocarbons and nitrogen oxides. These chemicals react to form a brownish mixture of ozone and other pollutants. Smog can irritate the eyes, throat, and lungs. It can also harm plants and other living things.

Another result of air pollution is acid rain. Rain is naturally slightly acidic, but rain that contains more acid than normal is known as **acid rain.** How does acid rain form? The burning of coal that contains a lot of sulfur produces sulfur oxides, substances composed of oxygen and sulfur. Acid rain forms when nitrogen oxides and sulfur oxides combine with water in the air to form nitric acid and sulfuric acid.

Acid rain is sometimes strong enough to damage the surfaces of buildings and statues. It also harms lakes and ponds. Acid rain can make water so acidic that many plants and animals can no longer live in it.

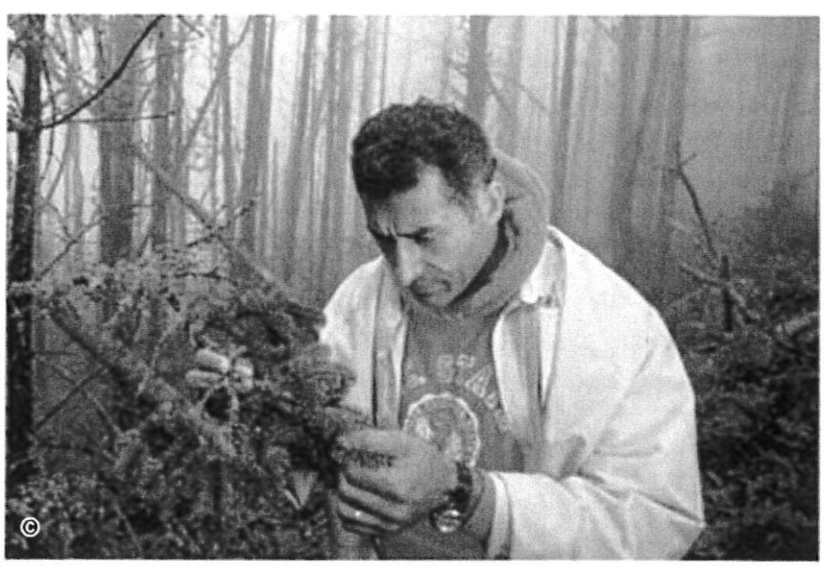


FIGURE 4
Results of Acid Rain
This scientist is studying trees damaged by acid rain. Needle-leafed trees such as pines and spruces are especially sensitive to acid rain. Acid rain may make tree needles turn brown or fall off.

Improving Air Quality

In the United States, the federal and state governments have passed a number of laws and regulations to reduce air pollution. The Environmental Protection Agency (EPA) monitors air pollutants in the United States. Air quality in this country has generally improved over the past 30 years. The amounts of most major air pollutants have decreased. Many newer cars cause less pollution than older models. Recently-built power plants are less polluting than power plants that have been in operation for many years.

However, there are now more cars on the road and more power plants burning fossil fuels than in the past. Unfortunately, the air in many American cities is still polluted. Voluntary measures, such as greater use of public transportation in place of driving, could reduce the total amount of air pollution produced. Many people think that stricter regulations are needed to control air pollution. Others argue that reducing air pollution can be very expensive and that the benefits of stricter regulations may not be worth the costs.

FIGURE 5
Public Tranportation
Public transportation, like the light rail system above, can reduce air pollution.

Reading Checkpoint **Explain one way that air quality could be improved.**

Section 1 Assessment

Vocabulary Skill Greek Word Origins Use what you know about the Greek prefix *photo-* to explain the meaning of *photochemical smog.*

Reviewing Key Concepts

HINT HINT HINT

1. a. Defining What is the atmosphere?
   b. Listing What are the four most common gases in dry air?
   c. Explaining Why are the amounts of gases in the atmosphere usually shown as percentages of dry air?

HINT HINT HINT

2. a. Describing What are three ways in which the atmosphere is important to life on Earth?
   b. Predicting How would the amount of carbon dioxide in the atmosphere change if there were no plants?
   c. Developing Hypotheses How would Earth be different without the atmosphere?

HINT HINT HINT

3. a. Identifying What human activity is responsible for the formation of smog and acid rain?
   b. Explaining What kinds of harm does photochemical smog cause?
   c. Inferring Do you think that photochemical smog levels are higher during the winter or during the summer? Explain.

Writing in Science

Summary Write a paragraph that summarizes in your own words how oxygen from the atmosphere is important. Include its importance to living things and in other processes.

Section 2

Integrating Environmental Science

Air Pressure

Reading Preview

Key Concepts

- What are some of the properties of air?
- What instruments are used to measure air pressure?
- How does increasing altitude affect air pressure and density?

Key Terms

- density
- pressure
- air pressure
- barometer
- mercury barometer
- aneroid barometer
- altitude

Target Reading Skill

Identifying Main Ideas As you read the Properties of Air section, write the main idea—the biggest or most important idea—in a graphic organizer like the one below. Then write two supporting details. The supporting details give examples of the main idea.

Main Idea

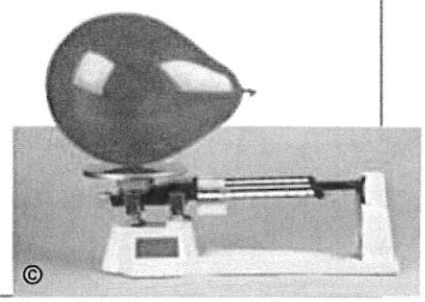
Because air has mass, it also . . .

Detail | Detail

Lab zone Standards Warm-Up

Does Air Have Mass?

1. Use a balance to find the mass of a deflated balloon.
2. Blow up the balloon fully and tie the neck closed. Predict whether the mass of the balloon plus the air you have compressed into it will differ from the mass of the deflated balloon.
3. Find the mass of the inflated balloon. Compare this to the mass of the deflated balloon. Was your prediction correct?

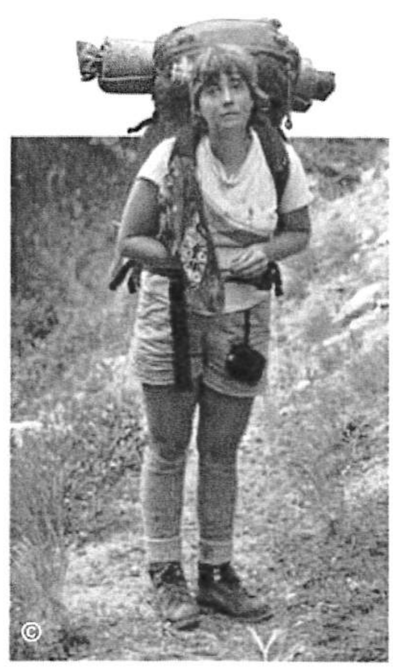


Think It Over

Drawing Conclusions What can you conclude about whether air has mass? Explain your conclusion.

The air is cool and clear—just perfect for an overnight hiking trip. You've stuffed your backpack with your tent, sleeping bag, stove, and food. When you hoist your pack onto your back, its weight presses into your shoulders. That pack sure is heavy! By the end of the day, you'll be glad to take it off and get rid of all that weight.

But here's a surprise: Even when you take off your pack, your shoulders will still have pressure on them. The weight of the atmosphere itself is constantly pressing on your body.



Like a heavy backpack pressing on your shoulders, the weight of the atmosphere causes air pressure. ▶

Properties of Air

It may seem to you that air has no mass. But in fact, air consists of atoms and molecules, which have mass. So air must have mass. **Because air has mass, it also has other properties, including density and pressure.**

Density Recall that the amount of mass in a given volume of air is its density. You can calculate the density of a substance by dividing its mass by its volume.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

If there are more molecules in a given volume, the density is greater. If there are fewer molecules, the density is less.

Pressure The force pushing on an area or surface is known as pressure. The weight of the atmosphere exerts a force on surfaces. Air pressure is the result of the weight of a column of air pushing down on an area. The column of air extends upward through the entire atmosphere, as shown in Figure 6.

The atmosphere is heavy. The weight of the column of air above your desk is about the same as the weight of a large schoolbus. So why doesn't air pressure crush your desk? The reason is that the molecules in air push in all directions—down, up, and sideways. The air pushing down on top of your desk is balanced by the air pushing up on the bottom of your desk.

Air pressure can change from day to day. A denser substance has more mass per unit volume than a less dense one. So denser air exerts more pressure than less dense air.

Reading Checkpoint: How does the density of air affect air pressure?

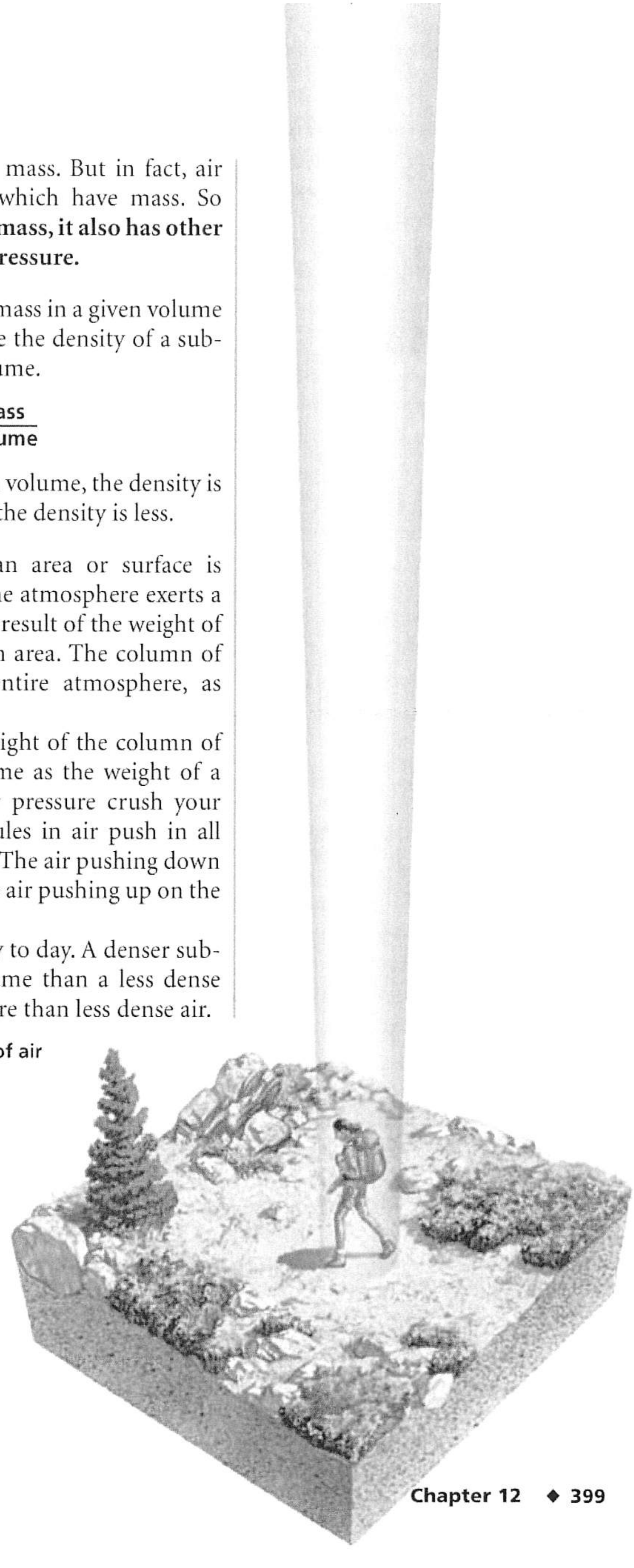
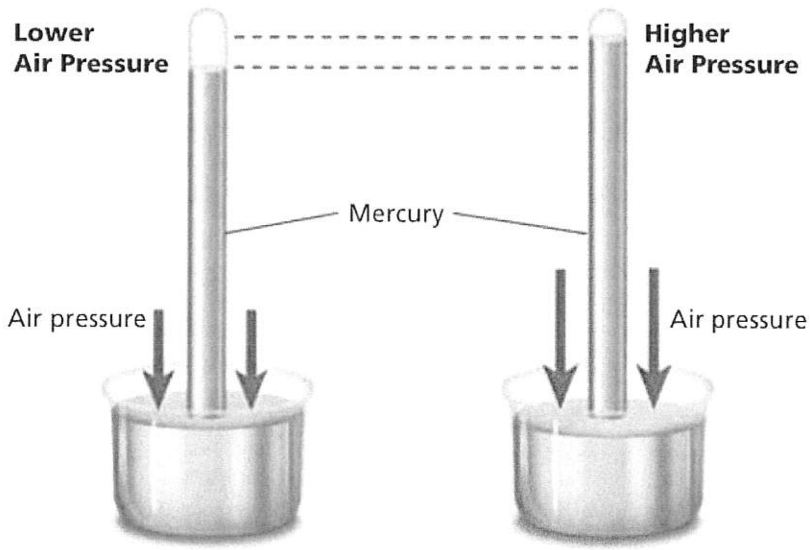


FIGURE 6
Air Pressure
There is a column of air above you all the time. The weight of the air in the atmosphere causes air pressure.

FIGURE 7
Mercury Barometer
Air pressure pushes down on the surface of the mercury in the dish, causing the mercury in the tube to rise. The air pressure is greater on the barometer on the right, so the mercury is higher in the tube.
Predicting *What happens to the level of mercury in the tube when the air pressure decreases?*



Go Online active art
For: Measuring Air Pressure activity
Visit: PHSchool.com
Web Code: cfp-4012

Measuring Air Pressure

A barometer (buh RAHM uh tur) is an instrument that is used to measure air pressure. **Two kinds of barometers are mercury barometers and aneroid barometers.**

Mercury Barometers Figure 7 shows the way a mercury barometer works. A mercury barometer consists of a glass tube open at the bottom end and partially filled with mercury. The space in the tube above the mercury is almost a vacuum—it contains very little air. The open end of the tube rests in a dish of mercury. The air pressure pushing down on the surface of the mercury in the dish is equal to the pressure exerted by the weight of the column of mercury in the tube. When the air pressure increases, it presses down more on the surface of the mercury. Greater air pressure forces the column of mercury higher. At sea level the mercury column is about 76 centimeters high, on average.

Aneroid Barometers If you have a barometer at home, it is probably an aneroid barometer. The word *aneroid* means "without liquid." An aneroid barometer (AN uh royd) has an airtight metal chamber. The metal chamber is sensitive to changes in air pressure. When air pressure increases, the thin walls of the chamber are pushed in. When the pressure drops, the walls bulge out. The chamber is connected to a dial by a series of springs and levers. As the shape of the chamber changes, the needle on the dial moves.

Units of Air Pressure Weather reports use several different units for air pressure. Most weather reports for the general public use inches of mercury. For example, if the column of mercury in a mercury barometer is 30 inches high, the air pressure is "30 inches of mercury" or just "30 inches."

National Weather Service maps indicate air pressure in millibars. One inch of mercury is approximately 33.87 millibars, so 30 inches of mercury is approximately equal to 1,016 millibars.

Reading Checkpoint What are two common units that are used to measure air pressure?

FIGURE 8
Aneroid Barometer
In an aneroid barometer, changes in air pressure cause the walls of an airtight metal chamber to flex in and out. This causes the needle on the barometer's dial to move.

Altitude and the Properties of Air

At the top of a mountain, the air pressure is less than the air pressure at sea level. **Altitude,** or elevation, is the distance above sea level, the average level of the surface of the oceans. **Air pressure decreases as altitude increases. As air pressure decreases, so does density.**

Altitude Affects Air Pressure Imagine a stack of books. Which book has more weight on it, the second book from the top or the book at the bottom? The second book from the top has only the weight of one book on top of it. The book at the bottom of the stack has the weight of all the books pressing on it.

Air at sea level is like the bottom book. Sea-level air has the weight of the whole atmosphere pressing on it. So air pressure is greater at sea level. Air near the top of the atmosphere is like the second book from the top. There, the air has less weight pressing on it, and thus has lower air pressure.

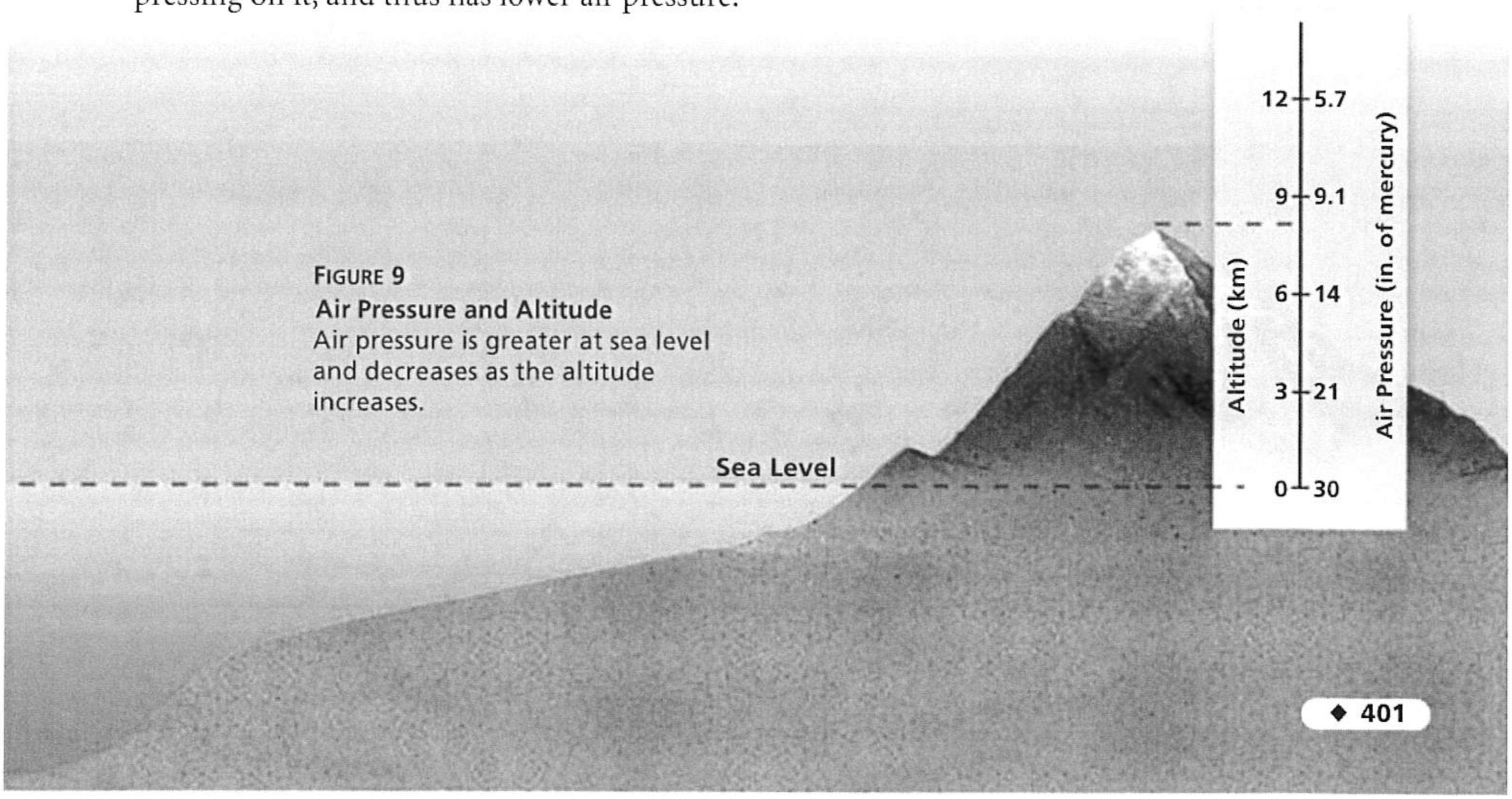
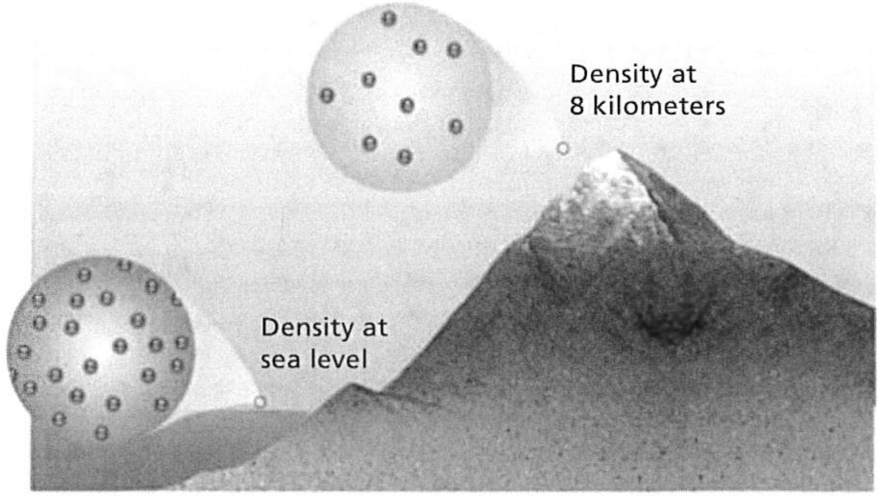


FIGURE 9
Air Pressure and Altitude
Air pressure is greater at sea level and decreases as the altitude increases.

FIGURE 10
Altitude and Density
The density of air decreases as altitude increases. Air at sea level has more gas molecules in each cubic meter than air at the top of a mountain.



Discovery Channel School
The Atmosphere
Video Preview
▶ Video Field Trip
Video Assessment

Altitude Also Affects Density As you go up through the atmosphere, the density of the air decreases. This means the gas molecules that make up the atmosphere are farther apart at high altitudes than they are at sea level. If you were near the top of a tall mountain and tried to run, you would quickly get out of breath. Why? The air contains 21 percent oxygen, whether you are at sea level or on top of a mountain. However, since the air is less dense at a high altitude, there are fewer oxygen molecules to breathe in each cubic meter of air than at sea level. So you would become short of breath quickly at high altitudes.

Reading Checkpoint **Why is it hard to breathe at the top of a mountain?**

Section 2 Assessment

Target Reading Skill Take Notes Review your notes for this section. What are two important ideas that you wrote under the heading Altitude and Properties of Air?

Reviewing Key Concepts

HINT 1. a. Defining What is air pressure?
HINT b. Explaining How does increasing the density of a gas affect its pressure?
HINT 2. a. Listing What are two instruments that can be used to measure air pressure?
HINT b. Measuring What units are commonly used to measure air pressure?
HINT c. Calculating How many millibars are equal to 27.23 inches of mercury?
HINT 3. a. Defining What is altitude?
HINT b. Relating Cause and Effect As altitude increases, how does air pressure change? How does density change?
HINT c. Predicting What changes in air pressure would you expect if you carried a barometer down a mine shaft?

Lab zone At-Home Activity

Model Air Pressure Here's how you can show your family that air has pressure. Fill a glass with water. Place a piece of cardboard over the top of the glass. Hold the cardboard in place with one hand as you turn the glass upside down. **CAUTION:** *Be sure the cardboard does not bend.* Now remove your hand from the cardboard. What happens? Explain to your family that the cardboard doesn't fall because the air pressure pushing up on it is greater than the weight of the water pushing down.

Section 3

Layers of the Atmosphere

Reading Preview

Key Concepts

- What are the four main layers of the atmosphere?
- What are the characteristics of each layer?

Key Terms

- troposphere
- stratosphere
- mesosphere
- thermosphere
- ionosphere
- exosphere

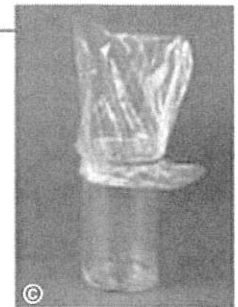
Target Reading Skill

Previewing Visuals Before you read this section, preview Figure 12. Then write at least two questions that you have about the diagram in a graphic organizer like the one below. As you read, answer your questions.

Layers of the Atmosphere

Q. Where is the ozone layer?
A.
Q.

Lab zone Standards Warm-Up



Is Air There?

1. Use a heavy rubber band to tightly secure a plastic bag over the top of a wide-mouthed jar.
2. Gently try to push the bag into the jar. What happens? Is the air pressure higher inside or outside the bag?
3. Remove the rubber band and line the inside of the jar with the plastic bag. Use the rubber band to tightly secure the edges of the bag over the rim of the jar.
4. Gently try to pull the bag out of the jar with your fingertips. What happens? Is the air pressure higher inside or outside the bag?

Think It Over

Predicting Explain your observations in terms of air pressure. How do you think differences in air pressure would affect a balloon as it traveled up through the atmosphere?

Imagine taking a trip upward into the atmosphere in a hot-air balloon. You begin on a warm beach near the ocean, at an altitude of 0 kilometers above sea level.

You hear a roar as the balloon's pilot turns up the burner to heat the air in the balloon. The balloon begins to rise, and Earth's surface gets farther and farther away. As the balloon rises to an altitude of 3 kilometers, you realize that the air is getting colder. As you continue to rise, the air gets colder still. At 6 kilometers you begin to have trouble breathing. The air is becoming less dense. It's time to go back down.

What if you could have continued your balloon ride up through the atmosphere? As you rose higher, the air pressure and temperature would change dramatically.

Scientists divide Earth's atmosphere into four main layers classified according to changes in temperature. These layers are the troposphere, the stratosphere, the mesosphere, and the thermosphere. The four main layers of the atmosphere are shown in Figure 12. Read on to learn more about each of these layers.

▲ Hot-air balloon

FIGURE 11
Weather Balloon
This weather balloon will carry a package of instruments to measure weather conditions high in the atmosphere.
Applying Concepts *Which is the first layer of the atmosphere that the balloon passes through on its way up?*

The Troposphere

You live in the inner, or lowest, layer of Earth's atmosphere, the **troposphere** (TROH puh sfeer). *Tropo-* means "turning" or "changing." Conditions in the troposphere are more variable than in the other layers. **The troposphere is the layer of the atmosphere in which Earth's weather occurs.**

Although hot-air balloons cannot travel very high into the troposphere, other types of balloons can. To measure weather conditions, scientists launch weather balloons that carry instruments up into the atmosphere. The balloons are not fully inflated before they are launched. Recall that air pressure decreases as you rise through the atmosphere. Leaving the balloon only partly inflated gives the gas inside the balloon room to expand as the air pressure outside the balloon decreases.

The depth of the troposphere varies from 16 kilometers above the equator to less than 9 kilometers above the North and South poles. Although it is the shallowest layer, the troposphere contains almost all of the mass of the atmosphere.

As altitude increases in the troposphere, the temperature decreases. On average, for every 1-kilometer increase in altitude, the air gets about 6.5 Celsius degrees cooler. At the top of the troposphere, the temperature stops decreasing and stays at about −60°C. Water here forms thin, feathery clouds of ice.

The Stratosphere

The **stratosphere** extends from the top of the troposphere to about 50 kilometers above Earth's surface. *Strato-* means "layer" or "spread out." **The stratosphere is the second layer of the atmosphere and contains the ozone layer.**

The lower stratosphere is cold, about −60°C. Surprisingly, the upper stratosphere is warmer than the lower stratosphere. Why is this? The middle portion of the stratosphere contains a layer of air where there is much more ozone than in the rest of the atmosphere. (Recall that ozone is the three-atom form of oxygen.) When the ozone absorbs energy from the sun, the energy is converted into heat, warming the air. The ozone layer is also important because it protects Earth's living things from dangerous ultraviolet radiation from the sun.

As a weather balloon rises through the stratosphere, the air pressure outside the balloon continues to decrease. The volume of the balloon increases. Finally, the balloon bursts, and the instrument package falls back to Earth's surface.

Reading Checkpoint **Why is the upper stratosphere warmer than the lower stratosphere?**

Go Online
PLANET DIARY
For: More on the ozone layer
Visit: PHSchool.com
Web Code: cfd-4013

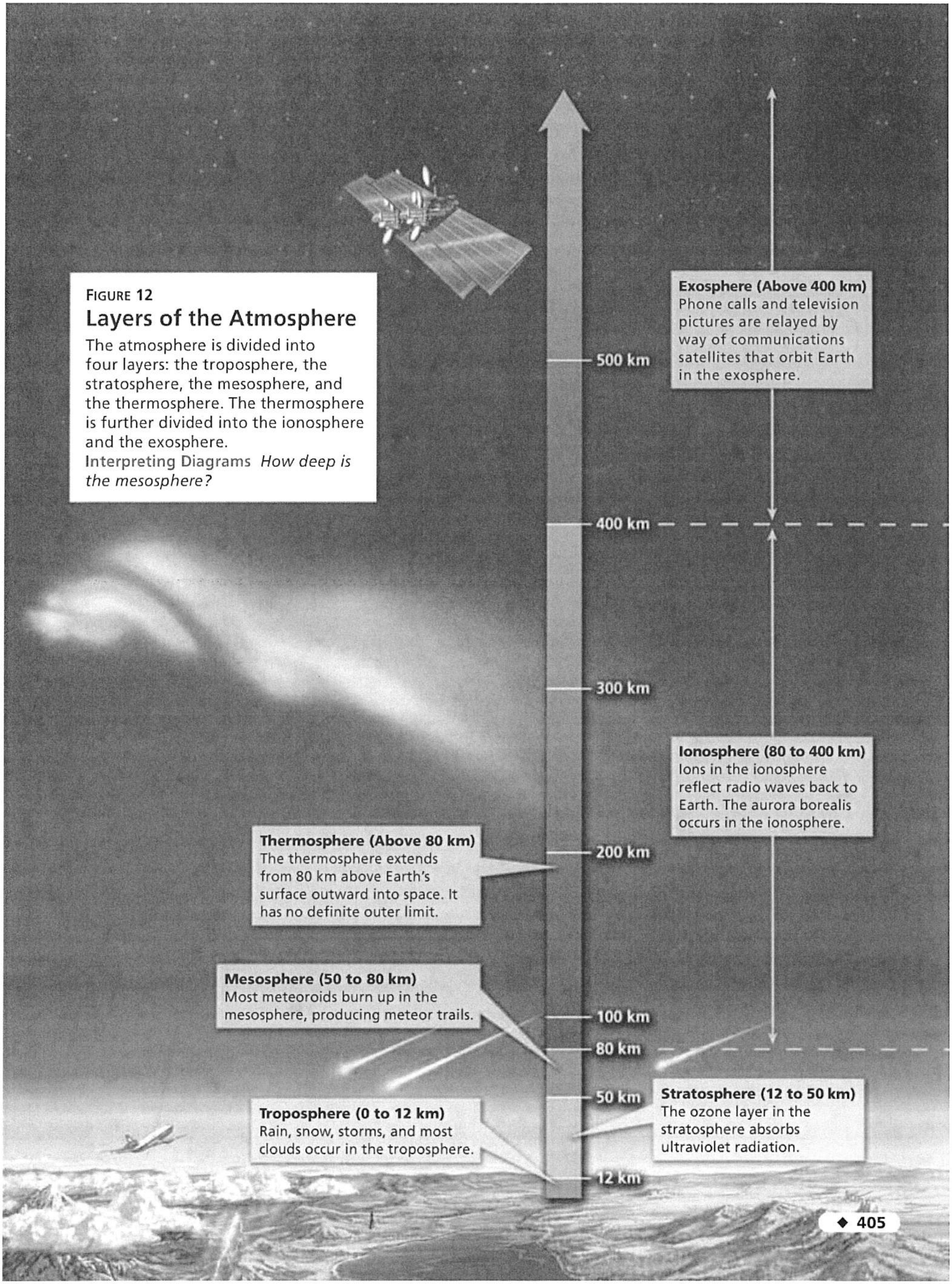


FIGURE 12
Layers of the Atmosphere
The atmosphere is divided into four layers: the troposphere, the stratosphere, the mesosphere, and the thermosphere. The thermosphere is further divided into the ionosphere and the exosphere.
Interpreting Diagrams *How deep is the mesosphere?*

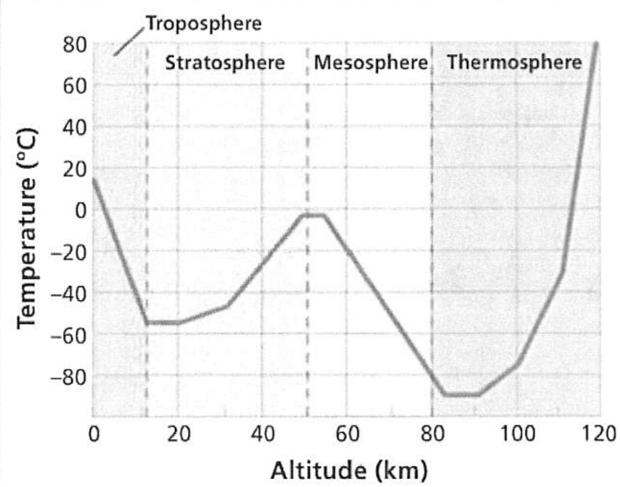
Math Analyzing Data

Changing Temperatures

The graph shows how temperatures in the atmosphere change with altitude. Use it to answer the questions below.

1. **Reading Graphs** What two variables are being graphed? In what unit is each measured?
2. **Reading Graphs** What is the temperature at the bottom of the stratosphere?
3. **Interpreting Data** Which layer of the atmosphere has the lowest temperature?
4. **Making Generalizations** Describe how temperature changes as altitude increases in the troposphere.

Temperature in the Atmosphere



The Mesosphere

Above the stratosphere, a drop in temperature marks the beginning of the next layer, the **mesosphere.** *Meso-* means "middle," so the mesosphere is the middle layer of the atmosphere. The mesosphere begins 50 kilometers above Earth's surface and ends at an altitude of 80 kilometers. In the outer mesosphere, temperatures approach –90°C.

The mesosphere is the layer of the atmosphere that protects Earth's surface from being hit by most meteoroids. Meteoroids are chunks of stone and metal from space. What you see as a shooting star, or meteor, is the trail of hot, glowing gases the meteoroid leaves behind in the mesosphere.

The Thermosphere

Near the top of the atmosphere, the air is very thin. At 80 kilometers above Earth's surface, the air is only about 0.001 percent as dense as the air at sea level. It's as though you took a cubic meter of air at sea level and expanded it into 100,000 cubic meters at the top of the mesosphere. **The outermost layer of Earth's atmosphere is the thermosphere.** The **thermosphere** extends from 80 kilometers above Earth's surface outward into space. It has no definite outer limit, but blends gradually with outer space.

The *thermo-* in thermosphere means "heat." Even though the air in the thermosphere is thin, it is very hot, up to 1,800°C. This is because sunlight strikes the thermosphere first. Nitrogen and oxygen molecules convert this energy into heat.

©

FIGURE 13
Aurora Borealis
The aurora borealis, seen from Fairbanks, Alaska, creates a spectacular display in the night sky.

Despite the high temperature, you would not feel warm in the thermosphere. An ordinary thermometer would show a temperature well below 0°C. Why is that? Temperature is the average amount of energy of motion of each molecule of a substance. The gas molecules in the thermosphere move very rapidly, so the temperature is very high. However, the molecules are spaced far apart in the thin air. There are not enough of them to collide with a thermometer and warm it very much.

The thermosphere is divided into two layers. The lower layer, called the **ionosphere** (eye AHN uh sfeer), begins about 80 kilometers above the surface and extends to about 400 kilometers. Energy from the sun causes gas molecules in the ionosphere to become electrically charged particles called ions. Radio waves bounce off ions in the ionosphere back to Earth's surface. Brilliant light displays, such as those shown in Figure 13, also occur in the ionosphere. In the Northern Hemisphere, these displays are called the Northern Lights, or the aurora borealis. Auroras are caused by particles from the sun that enter the ionosphere near the poles. These particles strike atoms in the ionosphere, causing them to glow.

Exo- means "outer," so the **exosphere** is the outer portion of the thermosphere. The exosphere extends from about 400 kilometers outward for thousands of kilometers.

Reading Checkpoint — What is the ionosphere?

Section 3 Assessment

Vocabulary Skill Greek Word Origins Add *tropo-* and *meso-* to your word origins chart. Then describe the four main layers of the atmosphere.

Reviewing Key Concepts

HINT
1. a. **Listing** List the four main layers of the atmosphere, beginning with the layer closest to Earth's surface.

HINT
b. **Classifying** What property is used to distinguish the layers of the atmosphere?

HINT
c. **Interpreting Diagrams** According to Figure 12, in which layer of the atmosphere do communications satellites orbit?

HINT
2. a. **Identifying** Give at least one important characteristic of each of the four main layers of Earth's atmosphere.

HINT
b. **Comparing and Contrasting** How does temperature change as height increases in the troposphere? Compare this to how temperature changes with height in the stratosphere.

HINT
c. **Applying Concepts** Why would you not feel warm in the thermosphere, even though temperatures can be up to 1,800°C?

Writing in Science

Cause and Effect Paragraph How do you think Earth's surface might be different if it had no atmosphere? Write a paragraph explaining your ideas.

Section 4

Energy in Earth's Atmosphere

Reading Preview

Key Concepts

- In what forms does energy from the sun travel to Earth?
- What happens to the sun's energy when it reaches Earth?

Key Terms

- electromagnetic waves
- radiation
- infrared radiation
- ultraviolet radiation
- scattering
- greenhouse effect

Target Reading Skill

Sequencing As you read, make a flowchart that shows how the sun's energy reaches Earth's surface. Put each step of the process in a separate box in the order in which it occurs.

How Earth's Atmosphere Gets Energy

Sun gives off energy.

↓

Energy travels to Earth as electromagnetic radiation.

↓

Lab zone Standards Warm-Up

Does a Plastic Bag Trap Heat?

1. Record the initial temperatures on two thermometers. (You should get the same readings.)
2. Place one of the thermometers in a plastic bag. Put a small piece of paper in the bag so that it shades the bulb of the thermometer. Seal the bag.
3. Cover the bulb of the second thermometer with a small piece of paper. Place both thermometers on a sunny window ledge or near a light bulb. Predict what you think will happen.
4. Wait five minutes. Then record the temperatures on the two thermometers.

Think It Over

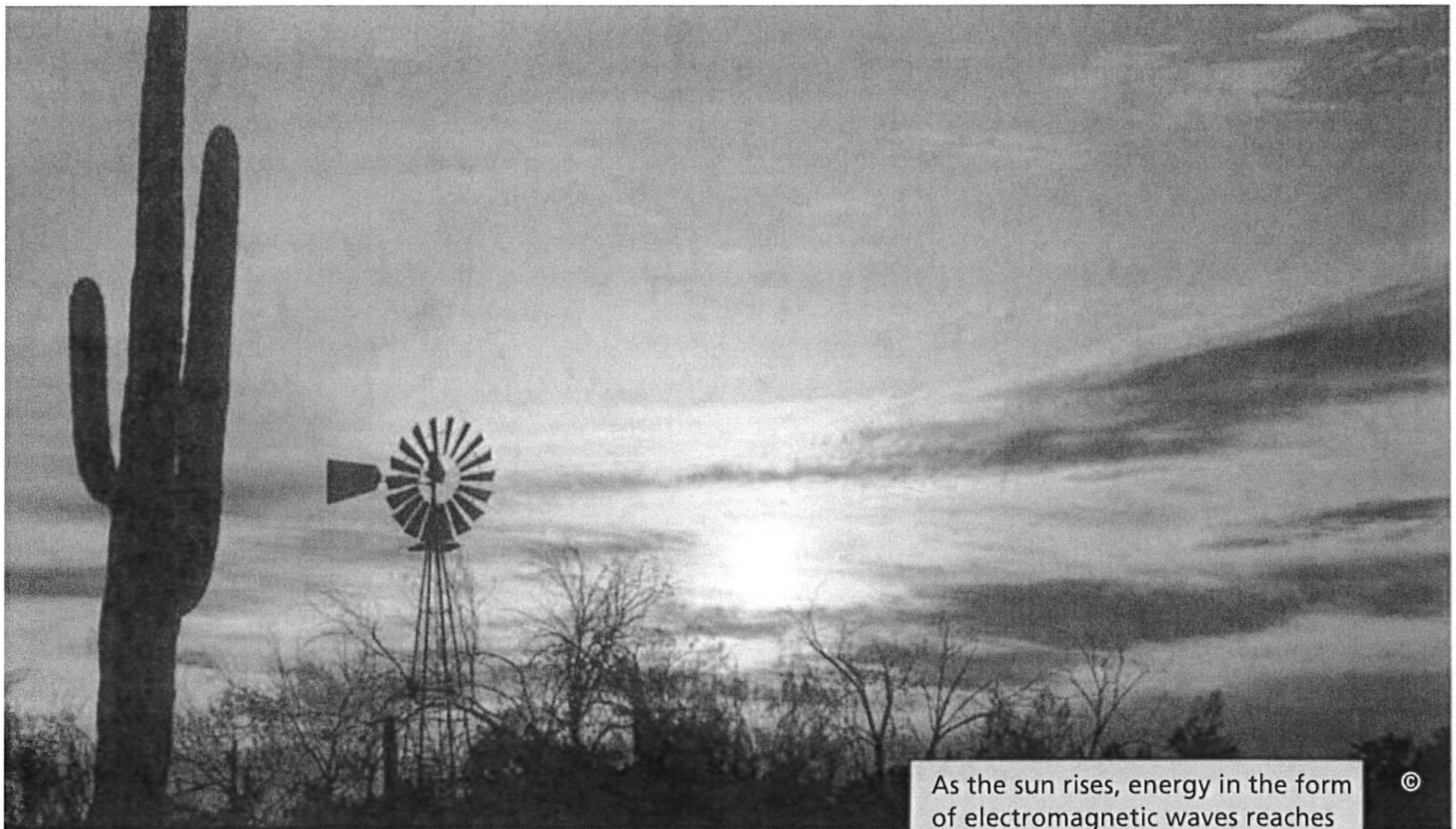
Measuring Were the two temperatures the same? How could you explain any difference?

In the deserts of California, summer nights can be chilly. In the morning, the sun is low in the sky and the air is cool. As the sun rises, the temperature increases. By noon it is quite hot. As you will learn in this chapter, heat is a major factor in the weather. The movement of heat in the atmosphere causes temperatures to change, winds to blow, and rain to fall.

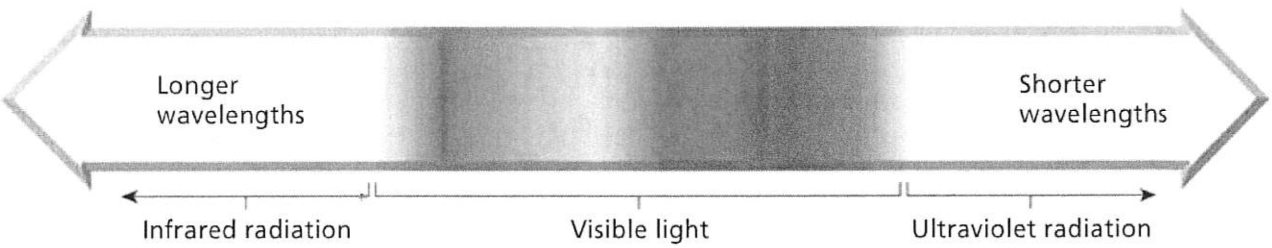
Energy From the Sun

Where does this heat come from? Nearly all the energy in Earth's atmosphere comes from the sun. This energy travels to Earth as **electromagnetic waves,** a form of energy that can move through the vacuum of space. Electromagnetic waves are classified according to wavelength, or distance between waves. **Radiation** is the direct transfer of energy by electromagnetic waves.

What kinds of energy do we receive from the sun? Is all of the energy the same? **Most of the energy from the sun travels to Earth in the form of visible light and infrared radiation. A small amount arrives as ultraviolet radiation.**



As the sun rises, energy in the form of electromagnetic waves reaches Earth's surface.



Visible Light Visible light includes all of the colors that you see in a rainbow: red, orange, yellow, green, blue, indigo, and violet. The different colors are the result of different wavelengths. Red and orange light have the longest wavelengths, while blue and violet light have the shortest wavelengths, as shown in Figure 14.

Non-Visible Radiation One form of electromagnetic energy, **infrared radiation,** has wavelengths that are longer than red light. Infrared radiation is not visible, but can be felt as heat. The sun also gives off **ultraviolet radiation,** which is an invisible form of energy with wavelengths that are shorter than violet light. Ultraviolet radiation can cause sunburns. This radiation can also cause skin cancer and eye damage. Solar radiation includes a full spectrum of wavelengths, from below the infrared to above the ultraviolet.

Reading Checkpoint **Which color of visible light has the longest wavelengths?**

FIGURE 14
Solar Radiation
Energy from the sun travels to Earth across a full spectrum of wavelengths.
Interpreting Diagrams *What type of radiation has wavelengths that are shorter than visible light?*

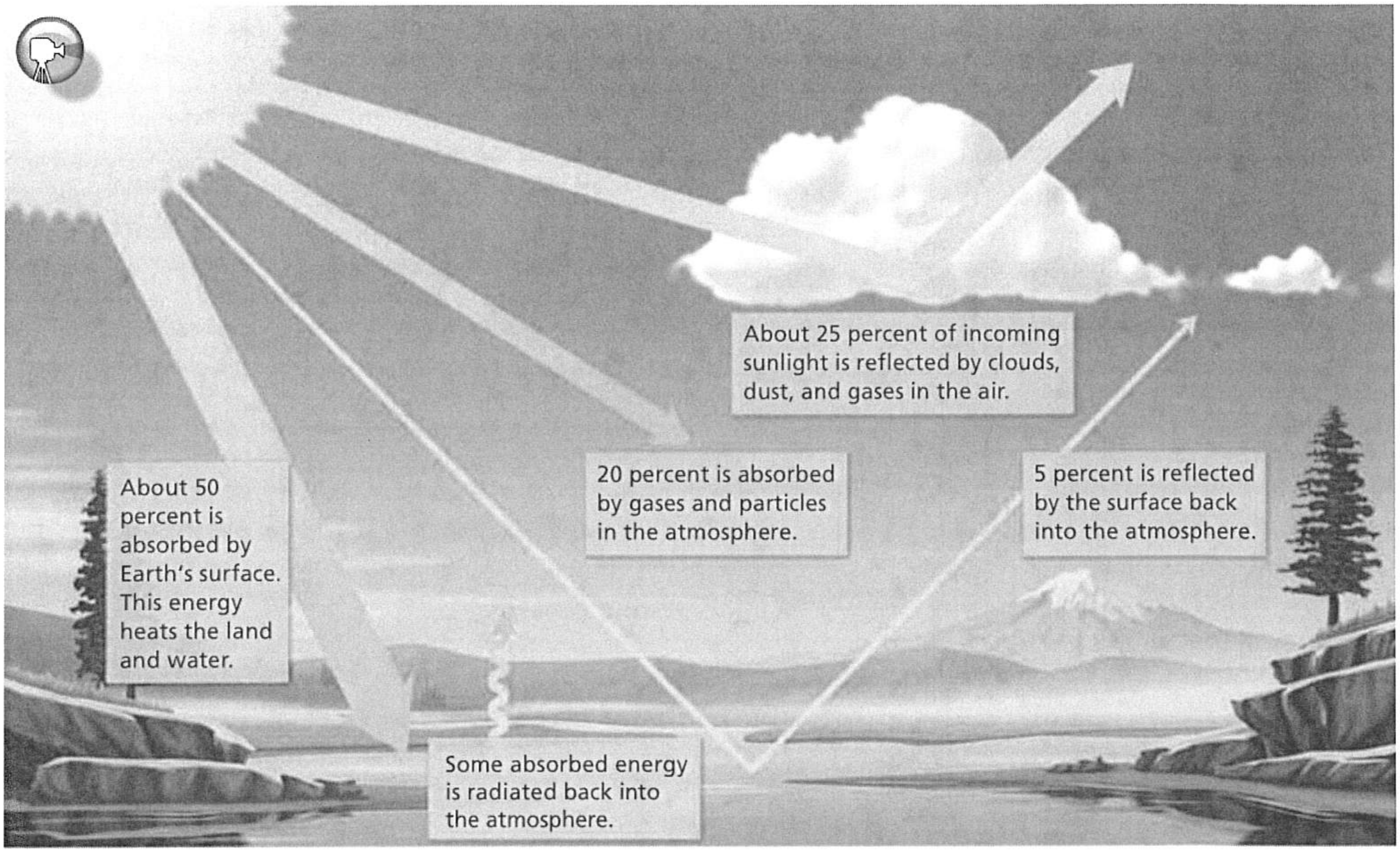


FIGURE 15
Energy in the Atmosphere
The sun's energy interacts with Earth's atmosphere and surface in several ways. About half is either reflected back into space or absorbed by the atmosphere. The rest reaches Earth's surface.

Energy in the Atmosphere

Before reaching Earth's surface, sunlight must pass through the atmosphere. The path of the sun's rays is shown in Figure 15. **Some sunlight is absorbed or reflected by the atmosphere before it can reach the surface. The rest passes through the atmosphere to the surface.**

Some solar radiation is absorbed by the atmosphere. The ozone layer in the stratosphere absorbs most of the ultraviolet radiation. Water vapor and carbon dioxide absorb some infrared radiation. Clouds, dust, and other gases also absorb energy.

Some sunlight is reflected. Clouds act like mirrors, reflecting sunlight back into space. Dust particles and gases in the atmosphere reflect light in all directions, a process called **scattering.** When you look at the sky, the light you see has been scattered by gas molecules in the atmosphere. Gas molecules scatter short wavelengths of visible light (blue and violet) more than long wavelengths (red and orange). Scattered light therefore looks bluer than ordinary sunlight. This is why the daytime sky looks blue.

When the sun is rising or setting, its light passes through a greater thickness of the atmosphere than when the sun is higher in the sky and looks yellow. More light from the blue end of the spectrum is removed by scattering before it reaches your eyes. The remaining light is mostly red and orange. The sun looks red, and clouds around it become very colorful.

Go Online
SCILINKS NSTA
For: Links on energy in Earth's atmosphere
Visit: www.SciLinks.org
Web Code: scn-0921

Energy at Earth's Surface

Some of the sun's energy reaches Earth's surface and is reflected back into the atmosphere. About half of the sun's energy, however, is absorbed by the land and water and changed into heat.

When Earth's surface is heated, it radiates most of the energy back into the atmosphere as infrared radiation. As shown in Figure 16, much of this infrared radiation cannot travel all the way through the atmosphere back into space. Instead, it is absorbed by water vapor, carbon dioxide, methane, and other gases in the air. The energy from the absorbed radiation heats the gases in the air. These gases form a "blanket" around Earth that holds heat in the atmosphere. The process by which gases hold heat in the air is called the **greenhouse effect**.

The greenhouse effect is a natural process that keeps Earth's atmosphere at a temperature that is comfortable for most living things. Over time, the amount of energy absorbed by the atmosphere and Earth's surface is nearly in balance with the amount of energy radiated into space. In this way, Earth's average temperatures remain fairly constant. However, as you will learn, emissions from human activities may be altering this process.

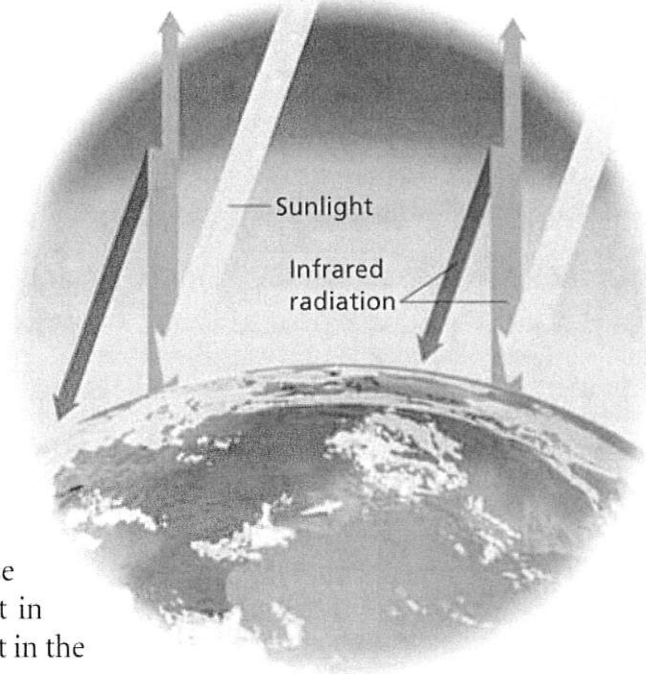


FIGURE 16
Greenhouse Effect
Sunlight travels through the atmosphere to Earth's surface. Earth's surface then gives off infrared radiation. Much of this energy is held by the atmosphere, warming it.

Reading Checkpoint What is the greenhouse effect?

Section 4 Assessment

Target Reading Skill Take Notes Use your notes to help you answer the following questions.

Reviewing Key Concepts

HINT

1. a. **Listing** List three forms of radiation from the sun.

HINT

   b. **Comparing and Contrasting** Which form of radiation from the sun has the longest wavelength? The shortest wavelength?

HINT

2. a. **Summarizing** What happens to most of the sunlight that reaches Earth?

HINT

   b. **Interpreting Diagrams** What percentage of incoming sunlight is reflected by clouds, dust, and gases in the atmosphere?

HINT

   c. **Applying Concepts** Why are sunsets red?

HINT

3. a. **Describing** What happens to the energy from the sun that is absorbed by Earth's surface?

   b. **Predicting** How might conditions on Earth be different without the greenhouse effect?

Lab zone At-Home Activity

Heating Your Home With an adult family member, explore the role radiation from the sun plays in heating your home. Does it make some rooms warmer in the morning? Are other rooms warmer in the afternoon? How does opening and closing curtains or blinds affect the temperature of a room? Explain your observations to your family.

Lab zone **Skills Lab**

Heating Earth's Surface

Problem

How do the heating and cooling rates of sand and water compare?

Skills Focus

developing hypotheses, graphing, drawing conclusions

Materials

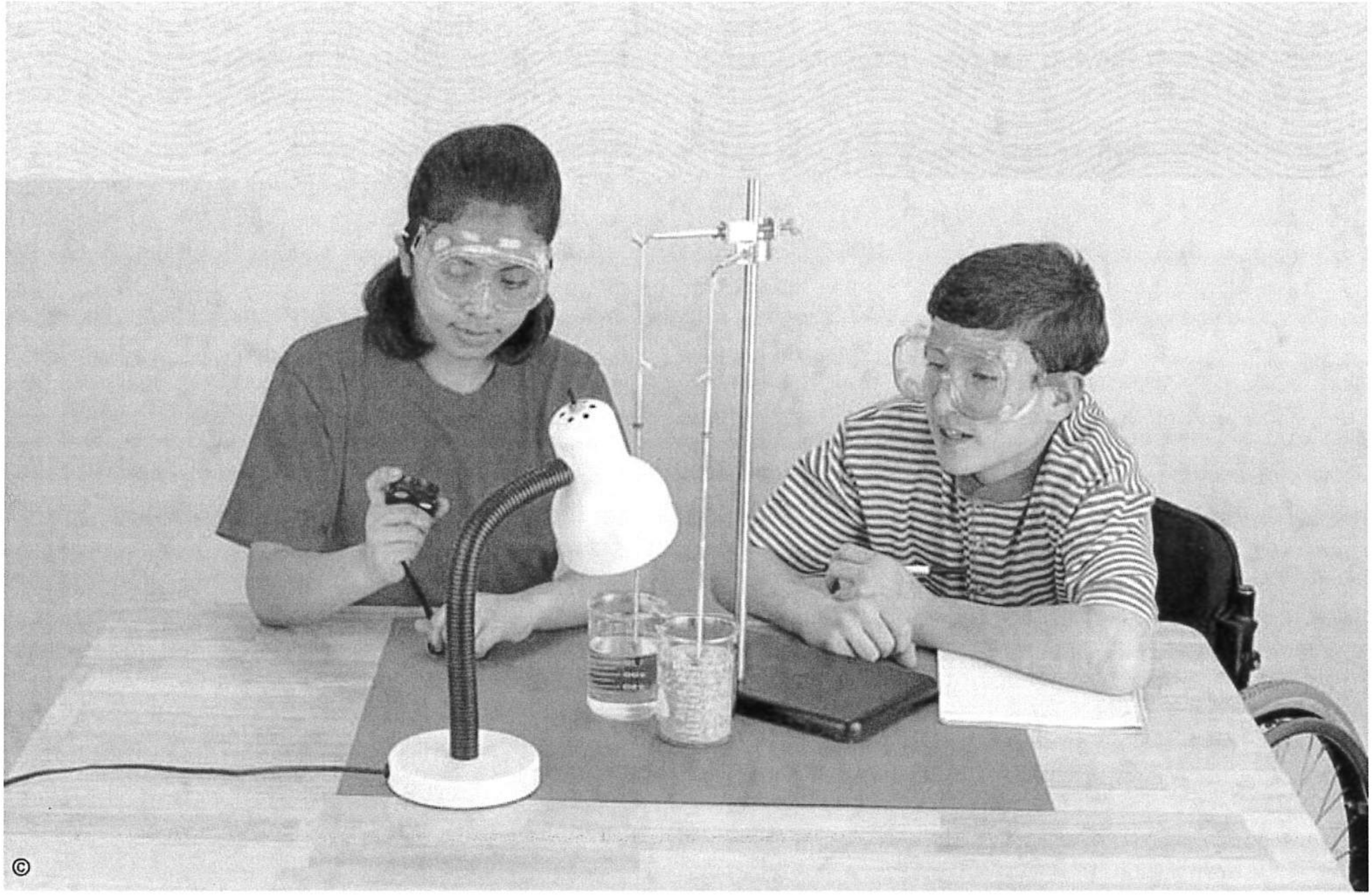
- 2 thermometers or temperature probes
- 2 beakers, 400-mL
- sand, 300 mL
- water, 300 mL
- lamp with 150-W bulb
- metric ruler
- clock or stopwatch
- string
- graph paper
- ring stand and two ring clamps

Procedure

1. Which do you think will heat up faster—sand or water? Record your hypothesis. Then follow these steps to test your hypothesis.
2. Copy the data table into your notebook. Add enough rows to record data for 15 minutes.
3. Fill one beaker with 300 mL of dry sand.
4. Fill the second beaker with 300 mL of water at room temperature.
5. Arrange the beakers side by side beneath the ring stand.
6. Place one thermometer in each beaker. If you are using a temperature probe, see your teacher for instructions.
7. Suspend the thermometers from the ring stand with string. This will hold the thermometers in place so they do not fall.
8. Adjust the height of the clamp so that the bulb of each thermometer is covered by about 0.5 cm of sand or water in a beaker.
9. Position the lamp so that it is about 20 cm above the sand and water. There should be no more than 8 cm between the beakers. **CAUTION:** *Be careful not to splash water onto the hot light bulb.*
10. Record the temperature of the sand and water in your data table.
11. Turn on the lamp. Read the temperature of the sand and water every minute for 15 minutes. Record the temperatures in the *Temperature With Light On* column in the data table.
12. Which material do you think will cool off more quickly? Record your hypothesis. Again, give reasons why you think your hypothesis is correct.
13. Turn the light off. Read the temperature of the sand and water every minute for another 15 minutes. Record the temperatures in the *Temperature With Light Off* column (16–30 minutes).

Data Table

Temperature With Light On (°C)			Temperature With Light Off (°C)		
Time (min)	Sand	Water	Time (min)	Sand	Water
Start			16		
1			17		
2			18		
3			19		
4			20		
5			21		



Analyze and Conclude

1. Graphing Draw two line graphs to show the data for the temperature change in sand and water over time. Label the horizontal axis from 0 to 30 minutes and the vertical axis in degrees Celsius. Draw both graphs on the same piece of graph paper. Use a dashed line to show the temperature change in water and a solid line to show the temperature change in sand.
2. Calculating Calculate the total change in temperature for each material.
3. Interpreting Data Based on your data, which material had the greater increase in temperature?
4. Drawing Conclusions What can you conclude about which material absorbed heat faster? How do your results compare with your hypothesis?
5. Interpreting Data Review your data again. In 15 minutes, which material cooled faster?
6. Drawing Conclusions How do these results compare to your second hypothesis?
7. Developing Hypotheses Based on your results, which do you think will heat up more quickly on a sunny day: the water in a lake or the sand surrounding it? After dark, which will cool off more quickly?
8. Communicating If your results did not support either of your hypotheses, why do you think the results differed from what you expected? Write a paragraph in which you discuss the results and how they compared to your hypotheses.

Design an Experiment

Do you think all solid materials heat up as fast as sand? For example, consider gravel, crushed stone, or different types of soil. Write a hypothesis about their heating rates as an "If ... then...." statement. With the approval and supervision of your teacher, develop a procedure to test your hypothesis. Was your hypothesis correct?

Section 5

Integrating Environmental Science

Heat Transfer

Reading Preview

Key Concepts

- How is temperature measured?
- In what three ways is heat transferred?
- How is heat transferred in the troposphere?

Key Terms

- thermal energy
- thermometer
- heat
- conduction
- convection
- convection current

Target Reading Skill

Outlining As you read, make an outline about how heat is transferred. Use the red headings for the main topics and the blue headings for the subtopics.

Heat Transfer
I. Thermal energy and temperature
A. Measuring temperature
B.
II. How heat is transferred
A.

Lab zone Standards Warm-Up

What Happens When Air Is Heated?

1. Use heavy scissors to cut the flat part out of an aluminum pie plate. Use the tip of the scissors to poke a small hole in the middle of the flat part of the plate.
2. Cut the part into a spiral shape, as shown in the photo. Tie a 30-centimeter piece of thread to the middle of the spiral.
3. Hold the spiral over a source of heat, such as a candle, hot plate, or incandescent light bulb.

Think It Over

Inferring What happened to the spiral? Why do you think this happened?

You pour a cup of steaming tea from a teapot. Your teacup is warm to the touch. Somehow, heat was transferred from one object (the cup) to another (your hand) that it was touching. This is an example of conduction, one of three ways that heat can be transferred. As you'll learn in this section, heat transfer in the troposphere plays an important role in influencing Earth's weather.

It takes only a small amount of energy to heat up a cup of tea. ▶

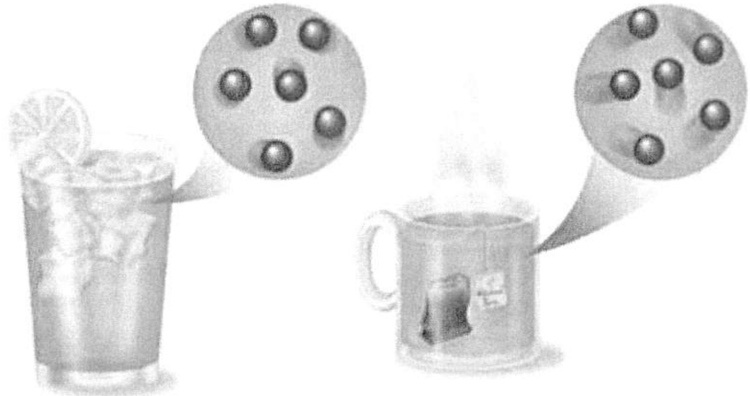


FIGURE 17
Movement of Molecules
The iced tea is cold, so its molecules move slowly. The herbal tea is hot, so its molecules move faster than the molecules in the iced tea. **Inferring** *Which liquid has a higher temperature?*

Thermal Energy and Temperature

The tea in the cup and in the teapot are the same temperature but have different amounts of total energy. To understand this, you need to know that all substances are made up of tiny particles that are constantly moving. The faster the particles are moving, the more energy they have. Figure 17 shows how the motion of the particles is related to the amount of energy they hold. Recall that temperature is the *average* amount of energy of motion of each particle of a substance. That is, temperature is a measure of how hot or cold a substance is. In contrast, the *total* energy of motion in the particles of a substance is called **thermal energy**. The hot tea in the teapot has more thermal energy than the hot tea in the cup because it has more particles.

Measuring Temperature Temperature is one of the most important factors affecting the weather. **Air temperature is usually measured with a thermometer.** A **thermometer** is a thin glass tube with a bulb on one end that contains a liquid, usually colored alcohol.

Thermometers work because liquids expand when they are heated and contract when they are cooled. When the air temperature increases, the temperature of the liquid in the bulb also increases. This causes the liquid to expand and rise up the tube of the thermometer.

Temperature Scales Temperature is measured in units called degrees. Two temperature scales are commonly used: the Celsius scale and the Fahrenheit scale. Scientists use the Celsius scale. On the Celsius scale, the freezing point of pure water is 0°C (read "zero degrees Celsius"). The boiling point of pure water at sea level is 100°C. Weather reports in the United States use the Fahrenheit scale. On the Fahrenheit scale, the freezing point of water is 32°F and the boiling point is 212°F.

Reading Checkpoint **Which temperature scale do scientists use?**

Math Skills

Converting Units

Temperatures in weather reports use the Fahrenheit scale, but scientists use the Celsius scale. Temperature readings can be converted from the Fahrenheit scale to the Celsius scale using the following equation:

$$°C = \frac{5}{9}(°F - 32)$$

If the temperature is 68°F, what is the temperature in degrees Celsius?

$$°C = \frac{5}{9}(68 - 32)$$

$$°C = 20°C$$

Practice Problem Use the equation to convert the following temperatures from Fahrenheit to Celsius: 35.0°F, 60.0°F, and 72.0°F.

Go Online
SCI LINKS NSTA

For: Links on heat transfer
Visit: www.SciLinks.org
Web Code: scn-0922

Lab zone **Try This Activity**

Temperature and Height

How much difference is there between air temperatures near the ground and higher up? Give reasons for your prediction.

1. Take all of your measurements outside at a location that is sunny all day.
2. Early in the morning, measure the air temperature 1 cm and 1.25 m above the ground. Record the time and temperature for each height. Repeat your measurements late in the afternoon.
3. Repeat Step 2 for two more days.
4. Graph your data for each height with temperature on the vertical axis and time of day on the horizontal axis. Use the same graph paper and same scale for each graph. Label each graph.

Interpreting Data At which height did the temperature vary the most? How can you explain the difference?

How Heat Is Transferred

Recall that **heat** is the transfer of thermal energy from a hotter object to a cooler one. **Heat is transferred in three ways within the atmosphere: radiation, conduction, and convection.**

Radiation Have you ever felt the warmth of the sun's rays on your face? You were feeling energy coming directly from the sun as radiation. Recall that radiation is the direct transfer of energy by electromagnetic waves.

Conduction Have you ever walked barefoot on hot sand? Your feet felt hot because heat moved directly from the sand into your feet. The direct transfer of heat from one substance to another substance that it is touching is called **conduction**. When a fast-moving sand molecule bumps into a slower-moving particle, the faster particle transfers some of its energy.

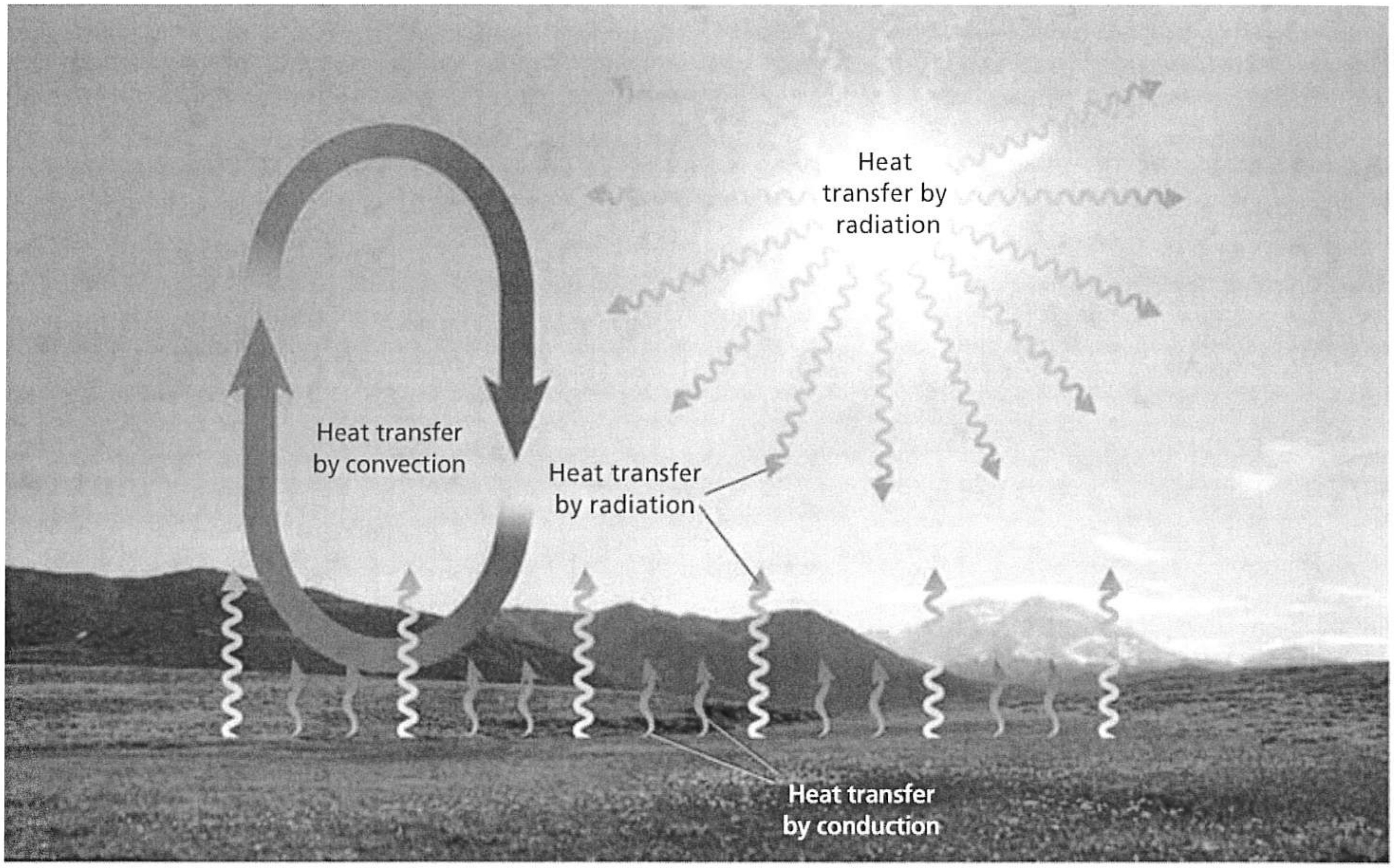
The closer together the particles in a substance are, the more effectively they can conduct heat. Conduction works well in some solids, such as metals, but not as well in liquids and gases. Air and water do not conduct heat very well.

Convection In fluids (liquids and gases), particles can move easily from one place to another. As the particles move, their energy goes along with them. The transfer of heat by the movement of a fluid is called **convection.**

Heating the Troposphere Radiation, conduction, and convection work together to heat the troposphere. During the day, the sun's radiation heats Earth's surface. The land becomes warmer than the air. Air near Earth's surface is warmed by both radiation and conduction. However, heat is not easily transferred from one air particle to another by conduction. Only the first few meters of the troposphere are heated by conduction. Thus, the air close to the ground is usually warmer than the air a few meters up.

Within the troposphere, heat is transferred mostly by convection. When the air near the ground is heated, its particles move more rapidly. As a result, they bump into each other and move farther apart. The heated air becomes less dense. Cooler, denser air sinks toward the surface, forcing the warmer air to rise. As the warm air rises, it cools and becomes more dense. This denser cool air sinks back toward the ground where it may be heated once again. This upward movement of warm air and the downward movement of cool air form **convection currents.** Convection currents move heat throughout the troposphere.

Reading Checkpoint **How is the air near Earth's surface heated?**



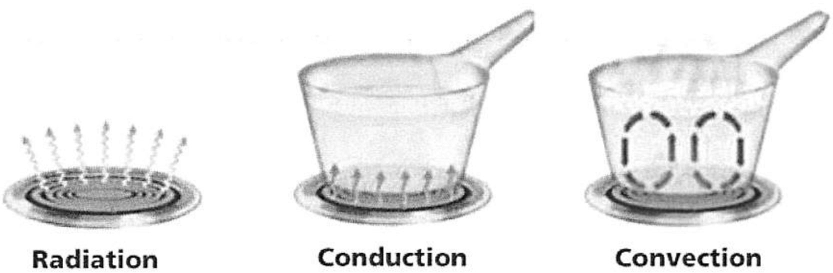


FIGURE 18
Heat Transfer
All three types of heat transfer—radiation, conduction, and convection—help to warm the troposphere.

Section 5 Assessment

Vocabulary Skill Greek Word Origins Use what you've learned about the Greek word *thermos* to explain the meaning of *thermal energy.*

Reviewing Key Concepts

1. a. Defining What is temperature? HINT
   b. Identifying What instrument is used to measure air temperature? HINT
   c. Comparing and Contrasting A pail of water is the same temperature as a lake. Compare the amount of thermal energy of the water in the lake and the water in the pail. HINT
2. a. Naming Name three ways that heat can be transferred. HINT
   b. Describing How do the three types of heat transfer work together to heat the troposphere? HINT
   c. Identifying What is the major way that heat is transferred in the troposphere? HINT
   d. Applying Concepts Explain how a hawk or eagle could use convection currents to soar upward without flapping its wings. HINT

Math Practice

3. Converting Units Use the equation from the Math Skills Activity to convert the following temperatures from Fahrenheit to Celsius: 52°F, 86°F, 77°F, and 97°F.

Section 6

Winds

Reading Preview

Key Concepts

- What causes winds?
- How do local winds and global winds differ?
- Where are the major global wind belts located?

Key Terms

- wind • anemometer
- wind-chill factor • local wind
- sea breeze • land breeze
- global wind • Coriolis effect
- latitude • jet stream

Target Reading Skill

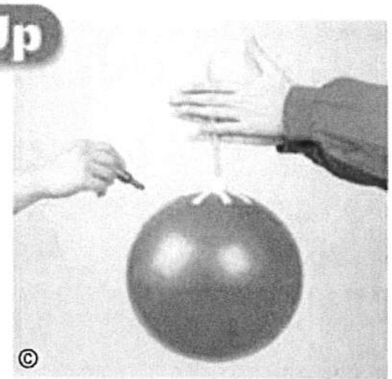
Relating Cause and Effect As you read, identify how the unequal heating of the atmosphere causes the air to move. Write the information in a graphic organizer like the one below.

Cause
Unequal heating of the atmosphere →

Effects
- Warm air expands, becomes less dense, and rises.
-
-

Lab zone Standards Warm-Up

Does the Wind Turn?



Do this activity with a partner. Let the ball represent a model of Earth and the marker represent wind.

1. Using heavy-duty tape, attach a pencil to a large smooth ball so that you can spin the ball from the top without touching it.
2. One partner should hold the pencil. Slowly turn the ball counterclockwise when seen from above.
3. While the ball is turning, the second partner should use a marker to try to draw a straight line from the "North Pole" to the "equator" of the ball. What shape does the line form?

Think It Over

Making Models If cold air were moving south from Canada into the continental United States, how would its movement be affected by Earth's rotation?

Have you ever flown a kite? Start by unwinding a few meters of string with the kite downwind from you. Have a friend hold the kite high overhead. Then, as your friend releases the kite, run directly into the wind. If you're lucky, the kite will start to rise. Once the kite is stable, you can unwind your string to let the wind lift the kite high into the sky. But what exactly is the wind that lifts the kite, and what causes it to blow?

A kite festival in Cape Town, South Africa ▶

What Is Wind?

Because air is a fluid, it can move easily from place to place. Differences in air pressure cause the air to move. A **wind** is the horizontal movement of air from an area of high pressure to an area of lower pressure. **Winds are caused by differences in air pressure.**

Most differences in air pressure are caused by the unequal heating of the atmosphere. Convection currents form when an area of Earth's surface is heated by the sun's rays. Air over the heated surface expands and becomes less dense. As the air becomes less dense, its air pressure decreases. If a nearby area is not heated as much, the air above the less-heated area will be cooler and denser. The cool, dense air with a higher pressure flows underneath the warm, less dense air. This forces the warm air to rise.

Measuring Wind Winds are described by their direction and speed. Wind direction is determined with a wind vane. The wind swings the wind vane so that one end points into the wind. The name of a wind tells you where the wind is coming from. For example, a south wind blows from the south toward the north. A north wind blows to the south.

Wind speed can be measured with an **anemometer** (an uh MAHM uh tur). An anemometer has three or four cups mounted at the ends of spokes that spin on an axle. The force of the wind against the cups turns the axle. A meter on the axle shows the wind speed.

Wind-Chill Factor On a warm day, a cool breeze can be refreshing. But in winter, the same breeze can make you feel uncomfortably cold. The wind blowing over your skin removes body heat. The stronger the wind, the colder you feel. The increased cooling a wind can cause is called the **wind-chill factor**.

Reading Checkpoint Toward what direction does a west wind blow?

Lab zone Try This Activity

Build a Wind Vane

1. Use scissors to cut out a pointer and a slightly larger tail fin from construction paper.
2. Make a slit 1 cm deep in each end of a soda straw.
3. Slide the pointer and tail fin into place on the straw, securing them with small pieces of tape.
4. Hold the straw on your finger to find the point at which it balances.
5. Carefully push a pin through the balance point and into the eraser of a pencil. Make sure the wind vane can spin freely.

Observing How can you use your wind vane to tell the direction of the wind?

FIGURE 19
Wind Speed
The anemometer on the right measures wind speed. The cups catch the wind, turning faster when the wind blows faster.

Local Winds

Have you ever noticed a breeze at the beach on a hot summer day? Even if there is no wind inland, there may be a cool breeze blowing in from the water. This breeze is an example of a local wind. **Local winds** are winds that blow over short distances. **Local winds are caused by the unequal heating of Earth's surface within a small area.** Local winds form only when large-scale winds are weak.

Sea Breeze Unequal heating often occurs along the shore of a large body of water. It takes more energy to warm up a body of water than it does to warm up an equal area of land. As the sun heats Earth's surface during the day, the land warms up faster than the water. As a result, the air over the land becomes warmer than the air over the water. The warm air expands and rises, creating a low-pressure area. Cool air blows inland from over the water and moves underneath the warm air, causing a sea breeze. A **sea breeze** or a lake breeze is a local wind that blows from an ocean or lake. Figure 20 shows a sea breeze.

Land Breeze At night, the process is reversed. Land cools more quickly than water, so the air over the land becomes cooler than the air over the water. As the warmer air over the water expands and rises, cooler air from the land moves beneath it. The flow of air from land to a body of water is called a **land breeze.**

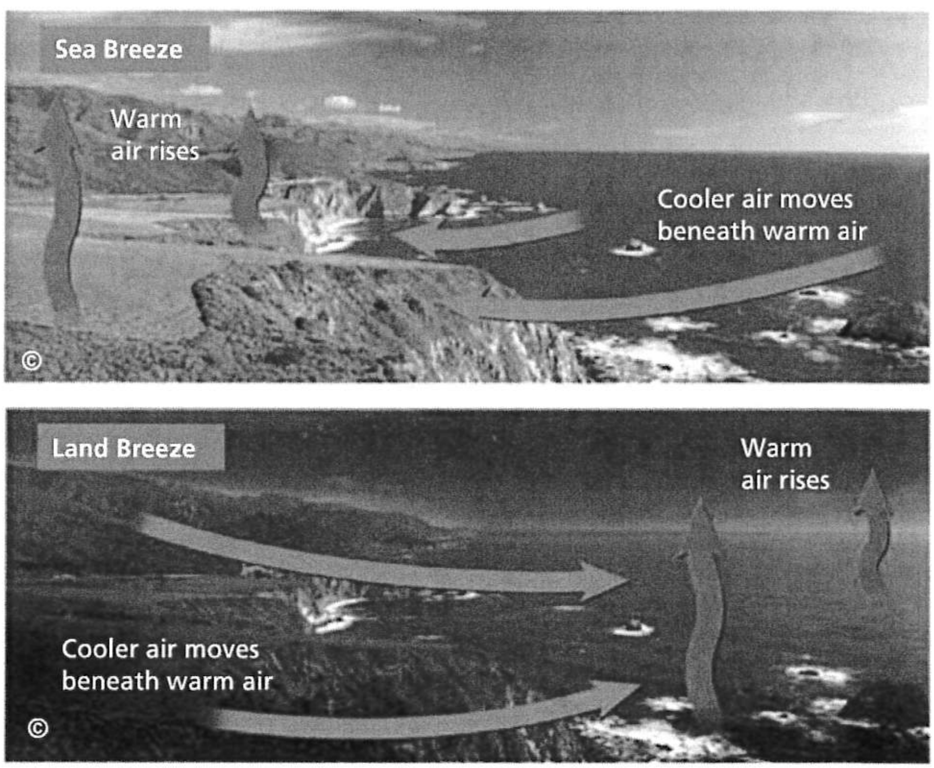


FIGURE 20
Local Winds
During the day, cool air moves from the sea to the land, creating a sea breeze. At night, cooler air moves from the land to the sea.
Forming Operational Definitions *What type of breeze occurs at night?*

Global Winds

Global winds are winds that blow steadily from specific directions over long distances. **Like local winds, global winds are created by the unequal heating of Earth's surface. But unlike local winds, global winds occur over a large area.** Recall how the sun's radiation strikes Earth. In the middle of the day near the equator, the sun is almost directly overhead. The direct rays from the sun heat Earth's surface intensely. Near the poles, the sun's rays strike Earth's surface at a lower angle. The sun's energy is spread out over a larger area, so it heats the surface less. As a result, temperatures near the poles are much lower than they are near the equator.

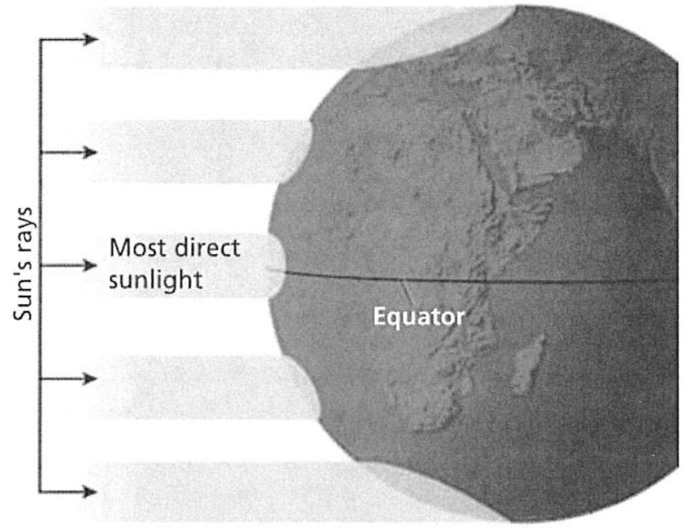


FIGURE 21
Angle of Sun's Rays
Near the equator, energy from the sun strikes Earth almost directly. Near the poles, the same amount of energy is spread out over a larger area.

Global Convection Currents How do global winds develop? Temperature differences between the equator and the poles produce giant convection currents in the atmosphere. Warm air rises at the equator, and cold air sinks at the poles. Therefore air pressure tends to be lower near the equator and greater near the poles. This difference in pressure causes winds at Earth's surface to blow from the poles toward the equator. Higher in the atmosphere, however, air flows away from the equator toward the poles. Those air movements produce global winds.

The Coriolis Effect If Earth did not rotate, global winds would blow in a straight line from the poles toward the equator. Because Earth is rotating, however, global winds do not follow a straight path. As the winds blow, Earth rotates from west to east underneath them, making it seem as if the winds have curved. The way Earth's rotation makes winds curve is called the **Coriolis effect** (kawr ee OH lis).

Because of the Coriolis effect, global winds in the Northern Hemisphere gradually turn toward the right. As Figure 22 shows, a wind blowing toward the south gradually turns toward the southwest. In the Southern Hemisphere, winds curve toward the left.

Reading Checkpoint **Which way do winds turn in the Southern Hemisphere?**

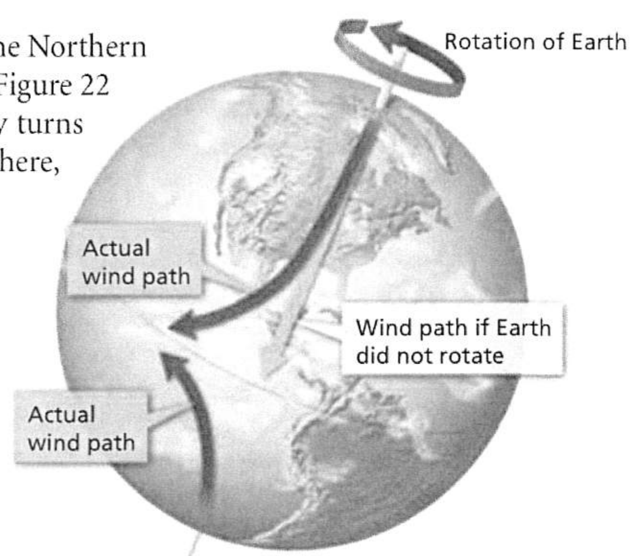


FIGURE 22
Coriolis Effect
As Earth rotates, the Coriolis effect turns winds in the Northern Hemisphere toward the right.

Global Wind Belts

Global convection currents and other factors combine to produce a pattern of calm areas and wind belts around Earth, as shown in Figure 24. The calm areas include the doldrums and the horse latitudes. **The major global wind belts are the trade winds, the polar easterlies, and the prevailing westerlies.**

Doldrums Near the equator, the sun heats the surface strongly. Warm air rises steadily, creating an area of low pressure. Cool air moves into the area, but is warmed rapidly and rises before it moves very far. There is very little horizontal motion, so the winds near the equator are very weak. Regions near the equator with little or no wind are called the doldrums.

Horse Latitudes Warm air that rises at the equator divides and flows both north and south. **Latitude** is distance from the equator, measured in degrees. At about 30° north and south latitudes, the air stops moving toward the poles and sinks. In each of these regions, another belt of calm air forms. Hundreds of years ago, sailors becalmed in these waters ran out of food and water for their horses and had to throw the horses overboard. Because of this, the latitudes 30° north and south of the equator came to be called the horse latitudes.

Trade Winds When the cold air over the horse latitudes sinks, it produces a region of high pressure. This high pressure causes surface winds to blow both toward the equator and away from it. The winds that blow toward the equator are turned west by the Coriolis effect. As a result, winds in the Northern Hemisphere between 30° north latitude and the equator generally blow from the northeast. In the Southern Hemisphere between 30° south latitude and the equator, the winds blow from the southeast. For hundreds of years, sailors relied on these winds to move ships carrying valuable cargoes from Europe to the West Indies and South America. As a result, these steady easterly winds are called the trade winds.

Prevailing Westerlies In the mid-latitudes, between 30° and 60° north and south, winds that blow toward the poles are turned toward the east by the Coriolis effect. Because they blow from the west to the east, they are called prevailing westerlies. The prevailing westerlies blow generally from the southwest in north latitudes and from the northwest in south latitudes. The prevailing westerlies play an important part in the weather of the United States.

FIGURE 23
Ocean Sailing
Sailing ships relied on global winds to speed their journeys to various ports around the world. **Applying Concepts** *How much effect do you think the prevailing winds have on shipping today?*

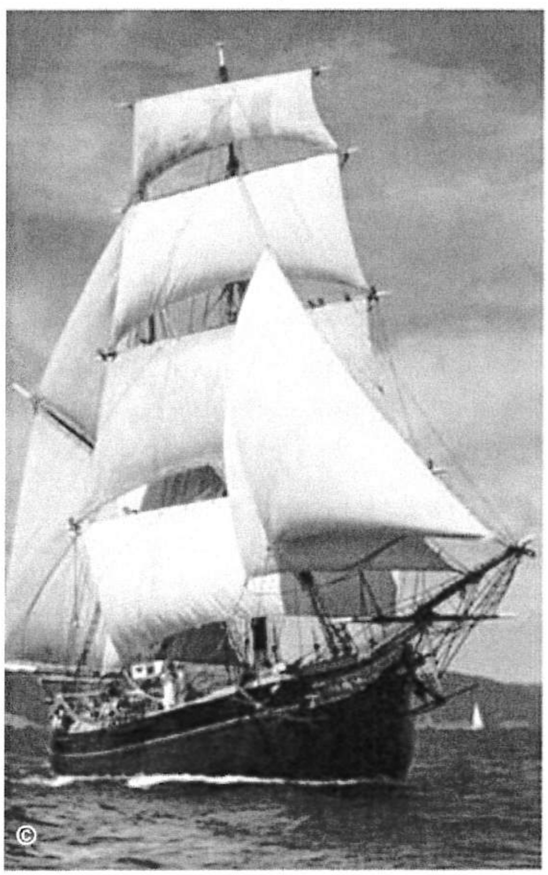


FIGURE 24
Global Winds

A series of wind belts circles Earth. Between the wind belts are calm areas where air is rising or falling. **Interpreting Diagrams** *Which global wind belt would a sailor choose to sail from eastern Canada to Europe?*

Go Online
active art
For: Global Winds activity
Visit: PHSchool.com
Web Code: cfp-4023

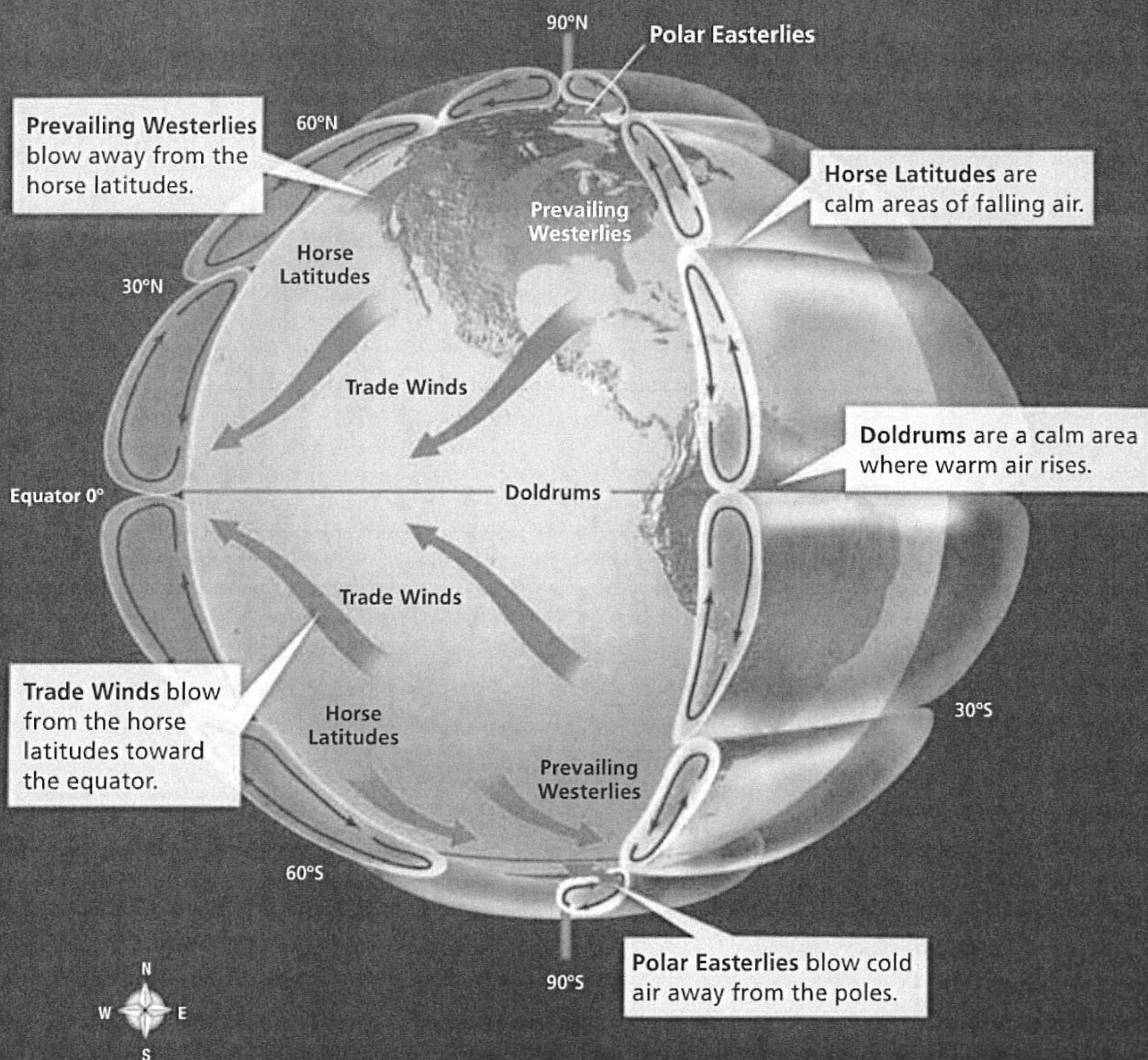
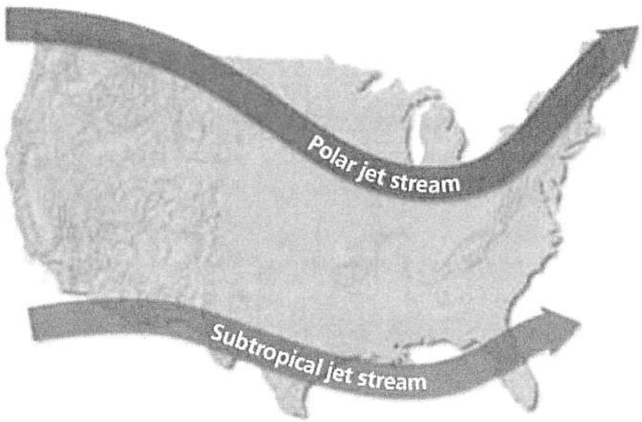


FIGURE 25
Jet Streams
The jet streams are high-speed bands of winds occurring at the top of the troposphere. By traveling east in a jet stream, pilots can save time and fuel.



Polar Easterlies Cold air near the poles sinks and flows back toward lower latitudes. The Coriolis effect shifts these polar winds to the west, producing the polar easterlies. The polar easterlies meet the prevailing westerlies at about 60° north and 60° south latitudes, along a region called the polar front. The mixing of warm and cold air along the polar front has a major effect on weather in the United States.

Jet Streams About 10 kilometers above Earth's surface are bands of high-speed winds called **jet streams.** These winds are hundreds of kilometers wide but only a few kilometers deep. Jet streams generally blow from west to east at speeds of 200 to 400 kilometers per hour, as shown in Figure 25. As jet streams travel around Earth, they wander north and south along a wavy path.

Reading Checkpoint What are the jet streams?

Section 6 Assessment

Target Reading Skill Take Notes Review your notes for this section. What important idea did you include about the Coriolis effect?

Reviewing Key Concepts

HINT HINT HINT HINT HINT HINT HINT HINT HINT

1. a. **Defining** What is wind?
   b. **Relating Cause and Effect** How is wind related to air temperature and air pressure?
   c. **Applying Concepts** It's fairly warm but windy outside. Use the concept of wind-chill factor to explain why it may be a good idea to wear a jacket.
2. a. **Defining** What are local winds?
   b. **Summarizing** What causes local winds?
   c. **Comparing and Contrasting** Compare the conditions that cause a sea breeze with those that cause a land breeze.
3. a. **Identifying** Name the three major global wind belts.
   b. **Describing** Briefly describe the three major global wind belts and where they are located.
   c. **Interpreting Diagrams** Use Figure 22 and Figure 24 to describe how the Coriolis effect influences the direction of the trade winds in the Northern Hemisphere. Does it have the same effect in the Southern Hemisphere? Explain.

Writing in Science

Explanation Imagine that you are a hot-air balloonist. You want to fly your balloon across the continental United States. To achieve the fastest time, would it make more sense to fly east-to-west or west-to-east? Explain how the prevailing winds influenced your decision.

Lab zone **Technology Lab**

• Tech & Design •

Measuring the Wind

Problem

Can you design and build an anemometer to measure the wind?

Design Skills

evaluating the design, redesigning

Materials

- pen
- round toothpick
- masking tape
- 2 wooden coffee stirrers
- meter stick
- corrugated cardboard sheet, 15 cm × 20 cm
- wind vane

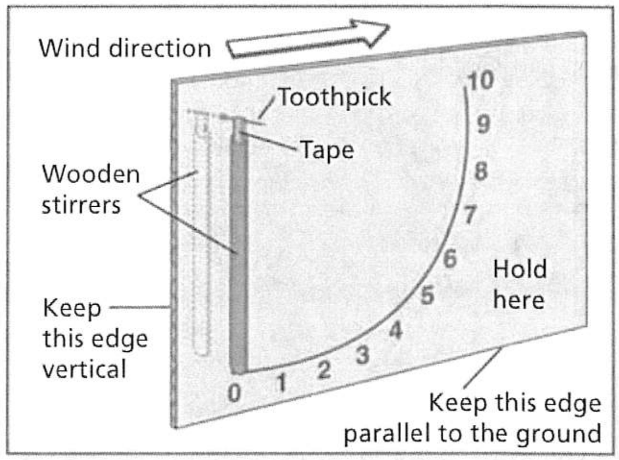
Procedure

1. Begin by making a simple anemometer that uses wooden coffee stirrers to indicate wind speed. On a piece of cardboard, draw a curved scale like the one shown in the diagram. Mark it in equal intervals from 0 to 10.
2. Carefully use the pen to make a small hole where the toothpick will go. Insert the toothpick through the hole.
3. Tape the wooden coffee stirrers to the toothpick as shown in the diagram, one on each side of the cardboard.
4. Copy the data table into your notebook.

Data Table

Location	Wind Direction	Wind Speed

5. Take your anemometer outside the school. Stand about 2–3 m away from the building and away from any corners or large plants.
6. Use the wind vane to find out what direction the wind is coming from. Hold your anemometer so that the card is straight, vertical, and parallel to the wind direction.



7. Observe the wooden stirrer on your anemometer for one minute. Record the highest wind speed that occurs during that time.
8. Repeat your measurements on all the other sides of the building. Record your data.

Analyze and Conclude

1. **Interpreting Data** Was the wind stronger on one side of the school than on the other sides? Explain your observations.
2. **Applying Concepts** Based on your data, which side of the building provides the best location for a door?
3. **Evaluating the Design** Do you think your anemometer accurately measured all of the winds you encountered? How could you improve its accuracy?
4. **Redesigning** What was the hardest part of using your anemometer? How could you change your design to make it more useful at very low or at very high wind speeds? Explain.
5. **Working With Design Constraints** How did having to use the materials provided by your teacher affect your anemometer? How would your design have changed if you could have used any materials you wanted to?

Communicate

Write a brochure describing the benefits of your anemometer. Make sure your brochure explains how the anemometer works and its potential uses.

Chapter 12 Study Guide

The BIG Idea

Weather and climate Air pressure and temperature vary with altitude and location, resulting in distinct atmospheric layers and predictable wind patterns.

1 The Air Around You

Key Concepts

Earth's atmosphere is made up of nitrogen, oxygen, carbon dioxide, water vapor, and many other gases, as well as liquid particles and solids.

Earth's atmosphere makes conditions on Earth suitable for living things.

Burning fossil fuels causes smog and acid rain.

Key Terms

• weather • atmosphere • ozone • water vapor
• pollutant • photochemical smog • acid rain

2 Air Pressure

Key Concepts

Because air has mass, it also has other properties, including density and pressure.

Two kinds of barometers are mercury barometers and aneroid barometers.

Air pressure decreases as altitude increases. As air pressure decreases, so does density.

Key Terms

• density • pressure • air pressure
• barometer • mercury barometer
• aneroid barometer • altitude

3 Layers of the Atmosphere

Key Concepts

Scientists divide Earth's atmosphere into four main layers: the troposphere, the stratosphere, the mesosphere, and the thermosphere.

Earth's weather occurs in the troposphere.

The stratosphere contains the ozone layer.

The mesosphere protects Earth's surface from most meteoroids.

The outermost layer of Earth's atmosphere is the thermosphere.

Key Terms

• troposphere • stratosphere • mesosphere
• thermosphere • ionosphere • exosphere

4 Energy in Earth's Atmosphere

Key Concepts

Most energy from the sun travels to Earth in the form of visible light.

Some sunlight is absorbed or reflected by the atmosphere before it can reach the surface.

When the surface is heated, it radiates energy back into the atmosphere as infrared radiation.

Key Terms

• electromagnetic waves • radiation
• infrared radiation • ultraviolet radiation
• scattering • greenhouse effect

5 Heat Transfer in the Atmosphere

Key Concepts

Air temperature is usually measured with a thermometer.

Heat is transferred in three ways: radiation, conduction, and convection.

Radiation, conduction, and convection work together to heat the troposphere.

Key Terms

• thermal energy • thermometer • heat
• conduction • convection • convection current

6 Winds

Key Concepts

Winds are caused by differences in air pressure.

Local winds are caused by the unequal heating of Earth's surface within a small area.

Global winds are created by the unequal heating of Earth's surface over a large area.

Major global wind belts are the trade winds, the polar easterlies, and the prevailing westerlies.

Key Terms

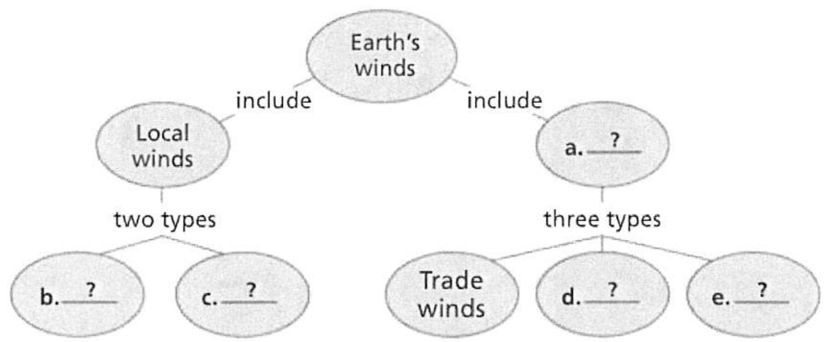
• wind • anemometer • wind-chill factor
• local wind • sea breeze • land breeze
• global wind • Coriolis effect • latitude
• jet stream

Review and Assessment

Go Online
PHSchool.com
For: Self-Assessment
Visit: PHSchool.com
Web Code: cpa-0012

Organizing Information

Concept Mapping Copy the concept map about Earth's winds onto a separate sheet of paper. Then complete it and add a title. (For more on concept mapping, see the Skills Handbook.)



Reviewing Key Terms

Choose the letter of the best answer.

HINT
1. The most abundant gas in the atmosphere is
   a. ozone.
   b. water vapor.
   c. oxygen.
   d. nitrogen.

HINT
2. Air pressure is typically measured with a
   a. thermometer.
   b. satellite.
   c. barometer.
   d. hot-air balloon.

HINT
3. The layers of the atmosphere are classified according to changes in
   a. altitude.
   b. temperature.
   c. air pressure.
   d. pollutants.

HINT
4. Energy from the sun travels to Earth's surface by
   a. radiation.
   b. convection.
   c. evaporation.
   d. conduction.

HINT
5. Rising warm air transports thermal energy by
   a. conduction.
   b. convection.
   c. radiation.
   d. condensation.

If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.

6. Weather is the condition of Earth's atmosphere at a particular time and place. HINT
7. The force pushing on an area or surface is known as density. HINT
8. Earth's weather occurs in the thermosphere. HINT
9. The ozone layer is found in the exosphere. HINT
10. The transfer of heat by the movement of a fluid is called conduction. HINT

Writing in Science

Descriptive Paragraph Suppose you are on a hot-air balloon flight to the upper levels of the troposphere. Describe how the properties of the atmosphere, such as air pressure and amount of oxygen, would change during your trip.

Discovery Channel School

The Atmosphere
Video Preview
Video Field Trip
▶ Video Assessment

Review and Assessment

Checking Concepts

11. Explain why it is difficult to include water vapor in a graph that shows the percentages of various gases in the atmosphere.

12. Name two ways in which carbon dioxide is added to the atmosphere.

13. Describe the temperature changes that occur as you move upward through the troposphere.

14. Describe examples of radiation, conduction, and convection from your daily life.

15. Explain how movements of air at the equator and poles produce global wind patterns.

Math Practice

16. **Converting Units** What is 60°F in degrees Celsius?

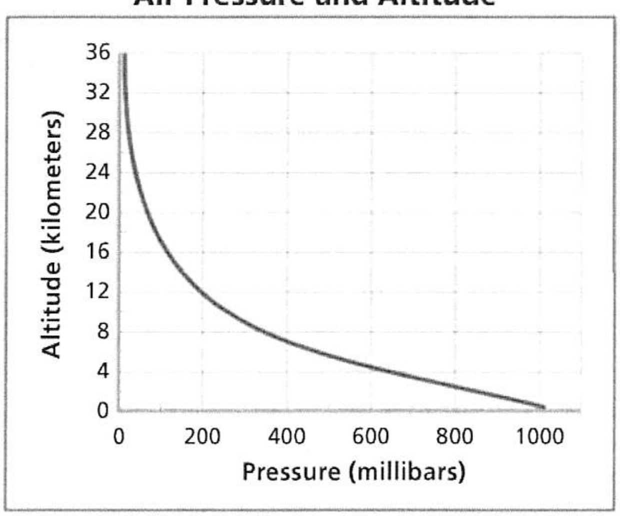
17. **Converting Units** What is 30°C in degrees Fahrenheit?

Thinking Critically

18. **Applying Concepts** Why can an aneroid barometer be used to indicate changes in elevation as well as air pressure?

19. **Reading Graphs** According to the graph below, what is the air pressure at an altitude of 4 km? In general, how does air pressure change with altitude?

Air Pressure and Altitude



20. **Inferring** Why are clouds at the top of the troposphere made of ice crystals rather than drops of water?

21. **Inferring** Venus has an atmosphere that is mostly carbon dioxide. How do you think the greenhouse effect has altered Venus?

22. **Relating Cause and Effect** What circumstances could cause a nighttime land breeze in a city near the ocean?

Applying Skills

Use the table below to answer the questions that follow.

The table shows the temperature at various altitudes above Omaha, Nebraska, on a January day.

Altitude (kilometers)	0	1.6	3.2	4.8	6.4	7.2
Temperature (°C)	0	−4	−9	−21	−32	−40

23. **Graphing** Make a line graph of the data in the table. Put temperature on the horizontal axis and altitude on the vertical axis. Label your graph.

24. **Reading Graphs** At about what height above the ground was the temperature −15°C?

25. **Reading Graphs** What was the approximate temperature 2.4 kilometers over Omaha?

26. **Calculating** Suppose an airplane was about 6.8 kilometers above Omaha on this day. What was the approximate temperature at 6.8 kilometers? How much colder was the temperature at 6.8 kilometers above the ground than at ground level?

Lab zone Chapter **Project**

Performance Assessment Decide how to present the findings from your weather station to the class. For example, you could put your graphs and predictions on a poster or use a computer to make a slide show. Make sure your graphs are neatly drawn and easy to understand.

Preparing for the CRCT

Test-Taking Tip

Reading All the Answer Choices

When you answer a multiple-choice question, always read *every* answer choice before selecting an answer. One choice may be more complete than another choice, which may be only partially correct. Also "all of the above" may be a possible answer. If you stop reading as soon as you find an answer that seems correct, you won't notice that "all of the above" is an option.

Sample Question

The troposphere is the layer of the atmosphere

A in which Earth's weather occurs.
B that is closest to Earth's surface.
C that contains most of the mass of the atmosphere.
D all of the above

Answer

If you know that Earth's weather occurs in the troposphere, you might be tempted to stop reading and select choice **A**. However, choices **B** and **C** are also true. Therefore, the most complete answer is **D**, all of the above.

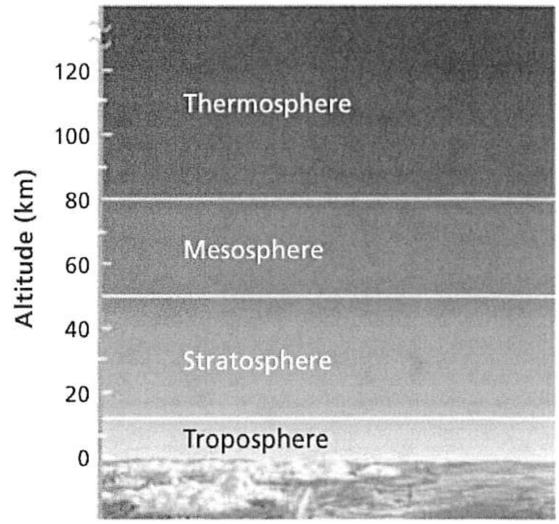
Choose the letter of the best answer.

1. What two gases make up approximately 99% of Earth's atmosphere?
   A nitrogen and carbon dioxide
   B oxygen and carbon dioxide
   C nitrogen and hydrogen
   D nitrogen and oxygen **S6E4**

2. In the troposphere, as altitude increases
   A air pressure decreases.
   B temperature decreases.
   C air density decreases.
   D all of the above **S6E6.a**

3. What is the main method by which heat is transferred within the troposphere?
   A radiation
   B conduction
   C convection
   D the greenhouse effect **S6E6.a**

Layers of the Atmosphere



Use the the diagram above and your knowledge of science to answer Questions 4 and 5.

4. Use the diagram to estimate the depth of the stratosphere.
   A about 50 kilometers
   B about 40 kilometers
   C about 30 kilometers
   D about 20 kilometers **S6E4**

5. According to the diagram, where is a meteoroid when it is 75 kilometers above Earth's surface?
   A the mesosphere
   B the stratosphere
   C the thermosphere
   D the troposphere **S6E4**

6. The ozone layer is found in the
   A troposphere.
   B stratosphere.
   C mesosphere.
   D thermosphere. **S6E4**

Constructed Response

7. What is acid rain, and why is it considered an environmental problem? Describe how acid rain forms and how it affects living things. Include in your answer the specific substances that combine to form acid rain. **S6E5.i**