Chapter 3

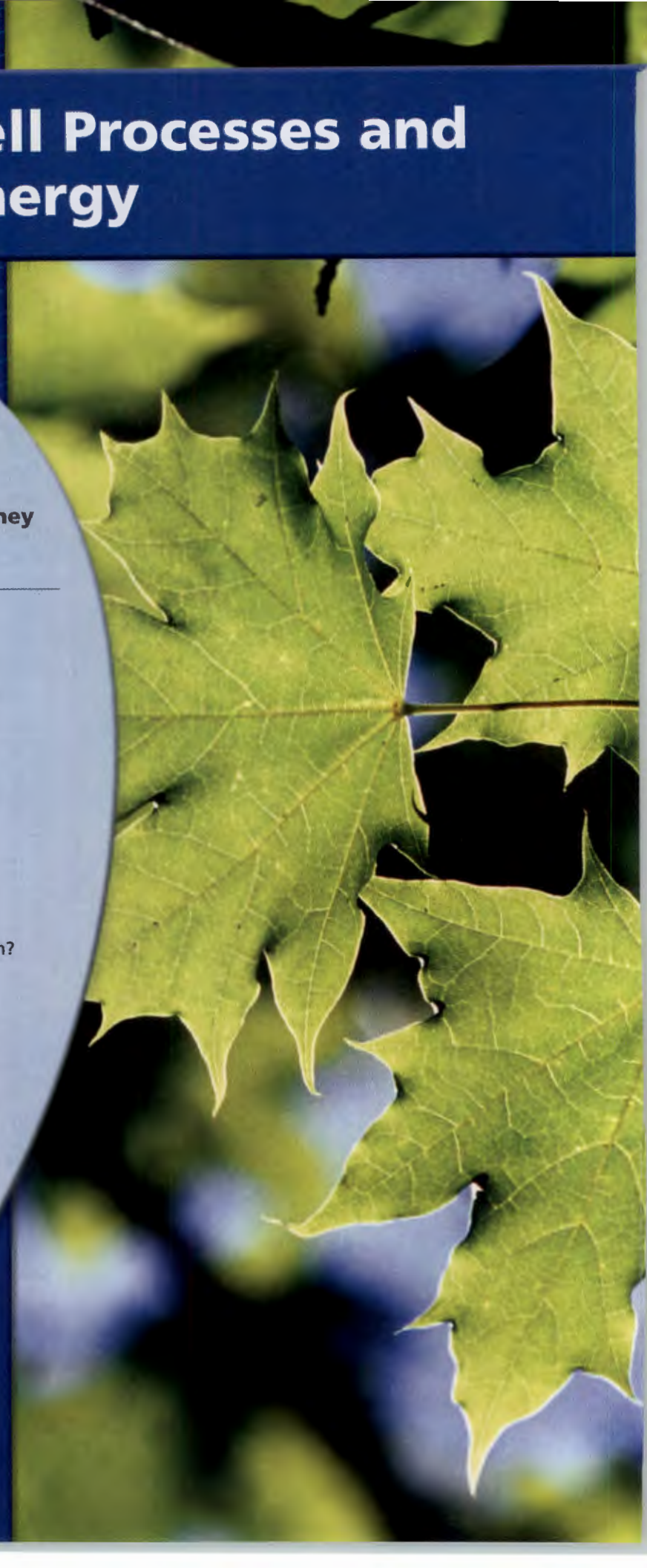
Cell Processes and Energy

The BIG Idea

Structure and Function

How do cells obtain energy they need to carry out all their functions?

Chapter Preview



Sunlight on these maple leaves powers the process of photosynthesis.

Lab zone™ Chapter Project

Shine On!

Every morning at sunrise, tiny living factories start a manufacturing process called photosynthesis. The power they use is sunlight. In this project, you will investigate how light affects one familiar group of photosynthesizers—plants.

Your Goal To determine how different lighting conditions affect the health and growth of plants

To complete the project, you will

- write up a plan to grow plants under different lighting conditions
- care for your plants daily and keep careful records of their health and growth for three weeks
- graph your data and draw conclusions about the effect of light on plant growth
- follow the safety guidelines in Appendix A

Plan It! Brainstorm with classmates to answer these questions: What different light conditions might you test? What plants will you use? How will you measure health and growth? How can you be sure your results are due to the light conditions? Write up your plan and submit it to your teacher.

Chemical Compounds in Cells

Reading Preview

Key Concepts

- What are elements and compounds?
- How is water important to the function of cells?
- What are the main kinds of organic molecules in living things?

Key Terms

- element • compound
- carbohydrate • lipid
- protein • amino acid
- enzyme • nucleic acid
- DNA • RNA

Target Reading Skill

Comparing and Contrasting

As you read, compare and contrast carbohydrates, lipids, and proteins in a table like the one below.

Type of Compound	Elements	Functions
Carbo-hydrate	Carbon, hydrogen, oxygen	
Lipid		
Protein		

Lab zone Discover Activity

What Is a Compound?

1. Your teacher will provide you with containers filled with various substances. All of the substances are chemical compounds.
2. Examine each substance. Read the label on each container to learn what each substance is made of.

Think It Over

Forming Operational Definitions Write a definition of what you think a chemical compound is.

Watch out—you are surrounded by particles that you can't see! Air is made up of millions of tiny particles. They bump into your skin, hide in the folds of your clothes, and whoosh into your nose every time you take a breath. In fact, you and the world around you, including the cells in your body, are composed of tiny particles. Some of these particles are elements, and others are compounds.

Elements and Compounds

You may not realize it, but air is a mixture of gases. These gases include both elements and compounds. Three gases in the air are oxygen, nitrogen, and carbon dioxide.

Elements Oxygen and nitrogen are examples of **elements.** **An element is any substance that cannot be broken down into simpler substances.** The smallest unit of an element is called an atom. An element is made up of only one kind of atom. The elements found in living things include carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur.

FIGURE 1
An Element
Sulfur is an element. In its pure form, it sometimes forms crystals.

Compounds Carbon dioxide is a **compound** made up of the elements carbon and oxygen. **When two or more elements combine chemically, they form a compound.** Most elements in living things occur in the form of compounds. The smallest unit of any compound is called a molecule. A molecule of carbon dioxide consists of one carbon atom and two oxygen atoms.

The Compound Called Water Like carbon dioxide, water is a compound. Each water molecule is made up of two hydrogen atoms and one oxygen atom. Water makes up about two thirds of your body. Water plays many important roles in cells. Water dissolves chemicals that cells need. **Most chemical reactions within cells could not take place without water.** Water also helps cells keep their size and shape. In fact, a cell without water would be like a balloon without air. In addition, because water changes temperature so slowly, it helps keep the temperature of cells from changing rapidly.

Organic and Inorganic Compounds Many compounds in living things contain the element carbon. Most compounds that contain carbon are called organic compounds. Compounds that don't contain carbon are called inorganic compounds. Water and sodium chloride, or table salt, are familiar examples of inorganic compounds.

Reading Checkpoint **How are inorganic compounds different from organic compounds?**

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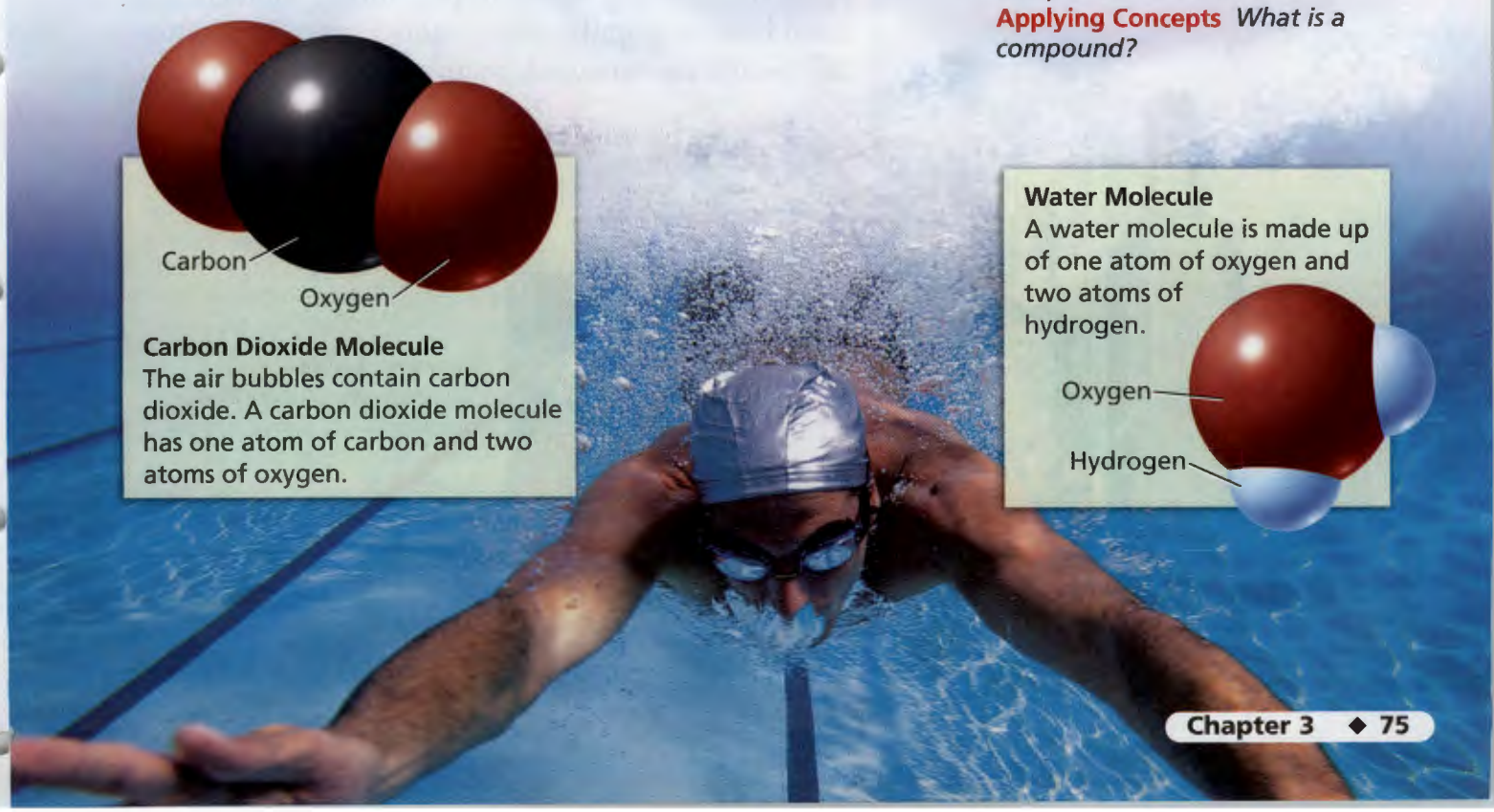
FIGURE 2
Molecules and Compounds
Carbon dioxide, which is found in the gas bubbles, is a chemical compound. So is water.
Applying Concepts *What is a compound?*



Carbon Dioxide Molecule
The air bubbles contain carbon dioxide. A carbon dioxide molecule has one atom of carbon and two atoms of oxygen.

Water Molecule
A water molecule is made up of one atom of oxygen and two atoms of hydrogen.

FIGURE 3 Starch
These potatoes contain a large amount of starch. Starch is a carbohydrate. The blue grains in the close-up are starch granules in a potato. The grains have been colored blue to make them easier to see.

Carbohydrates

Carbohydrates, lipids, proteins, and nucleic acids are important groups of organic compounds in living things. A **carbohydrate** is an energy-rich organic compound made of the elements carbon, hydrogen, and oxygen. Sugars and starches are carbohydrates.

Sugars are produced during the food-making process that takes place in plants. Foods such as fruits and some vegetables have a high sugar content. Sugar molecules can combine, forming large molecules called starches, or complex carbohydrates. Plant cells store excess energy in molecules of starch. Many foods that come from plants contain starch. These foods include potatoes, pasta, rice, and bread. When you eat those foods, your body breaks down the starch into glucose, a sugar that your cells can use to produce energy.

Carbohydrates are important components of some cell parts. For example, the cellulose found in the cell walls of plants is a type of carbohydrate. Carbohydrates are also found in cell membranes.

Lipids

Fats, oils, and waxes are all lipids. Like carbohydrates, **lipids** are energy-rich organic compounds made of carbon, hydrogen, and oxygen. Lipids contain even more energy than carbohydrates. Cells store energy in lipids for later use. For example, during winter, a dormant bear lives on the energy stored in fat. In addition, cell membranes are made mainly of lipids.

Reading Checkpoint **What are three kinds of lipids?**

FIGURE 4 Lipids
Olive oil, which comes from olives such as those shown here, is made mostly of lipids.
Making Generalizations
What elements are lipids composed of?

Proteins

What do a bird's feathers, a spider's web, and your fingernails have in common? All of these substances are made mainly of proteins. **Proteins** are large organic molecules made of carbon, hydrogen, oxygen, nitrogen, and, in some cases, sulfur. Foods that are high in protein include meat, eggs, fish, nuts, and beans.

Structure of Proteins Protein molecules are made up of smaller molecules called **amino acids.** Although there are only 20 common amino acids, cells can combine them in different ways to form thousands of different proteins. The kinds of amino acids and the order in which they link together determine the type of protein that forms. You can think of the 20 amino acids as being like the 26 letters of the alphabet. Those 26 letters can form thousands of words. The letters you use and their order determine the words you form. Even a change in one letter, for example, from *rice* to *mice,* creates a new word. Similarly, a change in the type or order of amino acids can result in a different protein.

Functions of Proteins Much of the structure of cells is made up of proteins. Proteins form parts of cell membranes. Proteins also make up many of the organelles within the cell.

The proteins known as enzymes perform important functions in the chemical reactions that take place in cells. An **enzyme** is a type of protein that speeds up a chemical reaction in a living thing. Without enzymes, many chemical reactions that are necessary for life would either take too long or not occur at all. For example, enzymes in your saliva speed up the digestion of food by breaking down starches into sugars in your mouth.

Reading Checkpoint **What is the role of enzymes in cells?**

Lab zone Try This Activity

What's That Taste?

Use this activity to discover one role that enzymes play in your body.

1. Put an unsalted soda cracker in your mouth. Chew it, but do not swallow. Note what the cracker tastes like.
2. Continue to chew the cracker for a few minutes, mixing it well with your saliva. Note how the taste of the cracker changes.

Inferring Soda crackers are made up mainly of starch, with little sugar. How can you account for the change in taste after you chewed the cracker for a few minutes?

FIGURE 5
Feathers Made of Protein
The feathers of this peacock are made mainly of protein.
Applying Concepts *What smaller molecules make up protein molecules?*

Nucleic Acids

Nucleic acids are very long organic molecules made of carbon, oxygen, hydrogen, nitrogen, and phosphorus. Nucleic acids contain the instructions that cells need to carry out all the functions of life.

There are two kinds of nucleic acids. Deoxyribonucleic acid (dee ahk see ry boh noo KLEE ik), or **DNA,** is the genetic material that carries information about an organism and is passed from parent to offspring. The information in DNA also directs all of the cell's functions. Most of the DNA in a cell is found in the chromatin in the nucleus. Ribonucleic acid (ry boh noo KLEE ik), or **RNA,** plays an important role in the production of proteins. RNA is found in the cytoplasm as well as in the nucleus.

Reading Checkpoint **What are the two kinds of nucleic acids? What are their functions?**

FIGURE 6 DNA in the Nucleus
A cell's nucleus (colored purple) contains most of the cell's DNA in its chromatin (colored red and yellow).

Section 1 Assessment

Target Reading Skill

Comparing and Contrasting Use the information in your table to help you answer the questions below.

Reviewing Key Concepts

1. a. **Defining** What is an element?
   b. **Comparing and Contrasting** How is a compound different from an element?
   c. **Classifying** A molecule of ammonia consists of one atom of nitrogen and three atoms of hydrogen. Is ammonia an element or a compound? Explain.
2. a. **Reviewing** What three important functions does water perform in cells?
   b. **Relating Cause and Effect** Suppose a cell is seriously deprived of water. How might this lack of water affect the cell's enzymes? Explain.
3. a. **Reviewing** What are four types of organic molecules found in living things?
   b. **Classifying** Which of the four types of organic molecules contain the element nitrogen?
   c. **Inferring** An organic compound contains only the elements carbon, hydrogen, and oxygen. Could this compound be a carbohydrate? Could it be a protein? Explain.

Lab zone At-Home Activity

Compounds in Food With family members, look at the "Nutrition Facts" labels on a variety of food products. Identify foods that contain large amounts of the following organic compounds: carbohydrates, proteins, and fats. Discuss with your family what elements make up each of these compounds and what roles they play in cells and in your body.

Lab zone **Consumer Lab**

Which Foods Are Fat-Free?

Problem

Some people want to limit their intake of fats, or lipids. How can you determine whether information about fats on a food label is accurate?

Skills Focus

interpreting data, inferring

Materials

- permanent marker
- 5 cotton swabs
- 5 different snack dips in their containers, including nutrition labels
- 5 fat-testing strips with color key
- watch or clock
- 5 small squares of paper towel

Procedure

1. Copy the data table on a sheet of paper. Record the brand names of the five snack dips in the table. **CAUTION:** *Do not taste the dips at any time.*
2. Examine the nutrition label on the container of each dip. Record the percentage of the Daily Value (% DV) of fat that the dip contains.
3. Look at other information on the container to see whether the dip is labeled "fat-free." Record this information in the table.
4. Obtain five fat-testing strips. Label each strip with the name of one of the dips.
5. Use a cotton swab to smear a bit of one dip onto the test square of the corresponding testing strip. After 30 seconds, gently wipe the dip from the strip with a paper towel.
6. To determine whether the sample contains fat, compare the test square with the color key. Record your observation in the table.
7. Repeat Steps 5–6 for each of the sample dips.

Analyze and Conclude

1. **Observing** According to the information on the containers, which dips had 0% fat? Which dips were labeled "fat-free"?
2. **Interpreting Data** Did the result shown on the test square always agree with the information on the dip's container?
3. **Inferring** Based on your results, what can you conclude about the accuracy of labels indicating that foods are fat-free?
4. **Communicating** Write a report for consumers that summarizes your results. Summarize the processes you used.

Design an Experiment

Protein test strips indicate *how much* protein is present in a food sample. Design an experiment to rank five food samples in the order of least protein to most protein. *Obtain your teacher's permission before carrying out your investigation.*

Data Table

Name of Dip	Percent Fat (% Daily Value)	Labeled Fat-Free?	Result of Test

Section 2

The Cell in Its Environment

Reading Preview

Key Concepts

- How do most small molecules cross the cell membrane?
- Why is osmosis important to cells?
- What is the difference between passive transport and active transport?

Key Terms

- selectively permeable
- diffusion • osmosis
- passive transport
- active transport

Target Reading Skill

Building Vocabulary

A definition states the meaning of a word or phrase. After you read the section, reread the paragraphs that contain definitions of Key Terms. Use all the information you have learned to write a definition of each Key Term in your own words.

Lab zone **Discover Activity**

How Do Molecules Move?

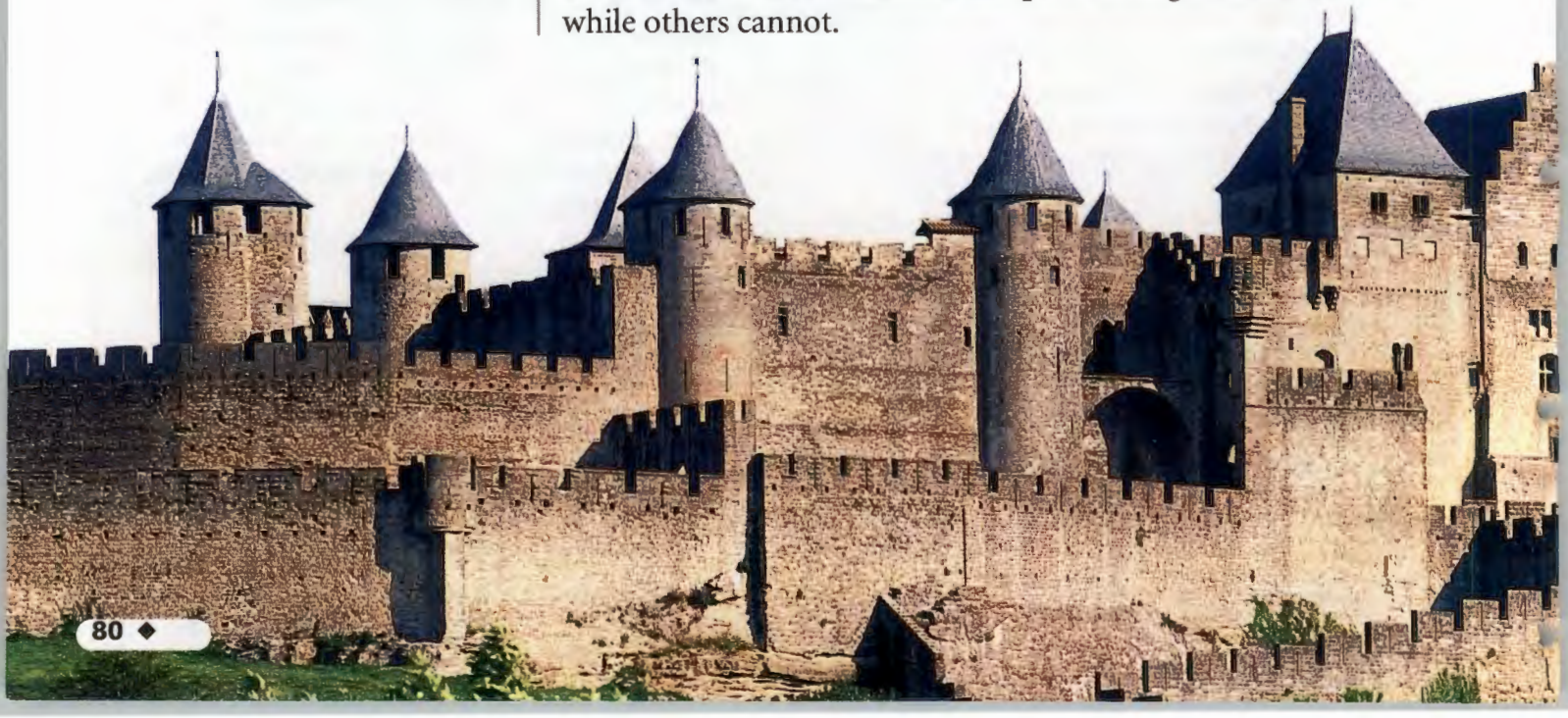
1. Stand with your classmates in locations that are evenly spaced throughout the classroom.
2. Your teacher will spray an air freshener into the room. When you first smell the air freshener, raise your hand.
3. Note how long it takes for other students to smell the scent.

Think It Over

Developing Hypotheses How was each student's distance from the teacher related to when he or she smelled the air freshener? Develop a hypothesis about why this pattern occurred.

As darkness fell, the knight urged his horse toward the castle. The weary knight longed for the safety of the castle, with its thick walls of stone and strong metal gates. The castle's gatekeeper opened the gates and slowly lowered the drawbridge. The horse clopped across the bridge, and the knight sighed with relief. Home at last!

Like ancient castles, cells have structures that protect their contents from the world outside. All cells are surrounded by a cell membrane that separates the cell from the outside environment. The cell membrane is **selectively permeable,** which means that some substances can pass through the membrane while others cannot.



Cells, like castles, must let things enter and leave. Cells must let in needed materials, such as oxygen and food molecules. In contrast, waste materials must move out of cells. Oxygen, food molecules, and waste products all must pass through the cell membrane.

Diffusion

Substances that can move into and out of a cell do so by one of three methods: diffusion, osmosis, or active transport. **Diffusion is the main method by which small molecules move across the cell membrane.** **Diffusion** (dih FYOO zhun) is the process by which molecules move from an area of higher concentration to an area of lower concentration. The concentration of a substance is the amount of the substance in a given volume. For example, suppose you dissolve 1 gram of sugar in 1 liter of water. The concentration of the sugar solution is 1 gram per liter.

If you did the Discover activity, you observed diffusion in action. The area where the air freshener was sprayed had many molecules of freshener. The molecules gradually moved from this area of higher concentration to the other parts of the classroom, where there were fewer molecules of freshener—and thus a lower concentration.

What Causes Diffusion? Molecules are always moving. As they move, the molecules bump into one another. The more molecules there are in an area, the more collisions there will be. Collisions cause molecules to push away from one another. Over time, the molecules of a substance will continue to spread out. Eventually, they will be spread evenly throughout the area.

Math Skills

Ratios

The concentration of a solution can be expressed as a ratio. A ratio compares two numbers. It tells you how much you have of one item in comparison to another. For example, suppose you dissolve 5 g of sugar in 1 L of water. You can express the concentration of the solution in ratio form as 5 g : 1 L, or 5 g/L.

Practice Problem Suppose you dissolve 7 g of salt in 1 L of water. Express the concentration of the solution as a ratio.

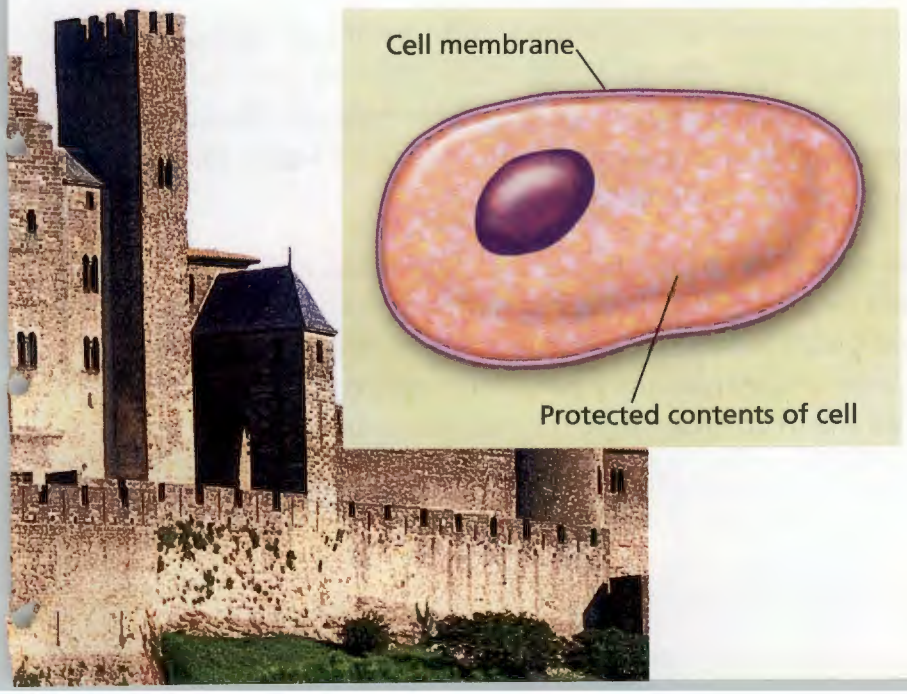
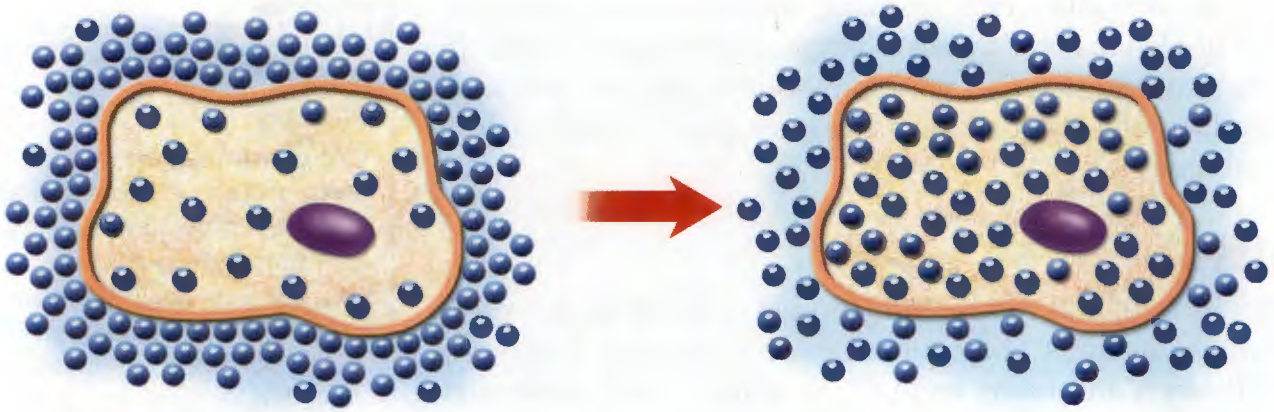


FIGURE 7
A Selective Barrier
The walls of a castle protected the inhabitants within, and the castle gatekeeper allowed only certain people to pass through. Similarly, the cell membrane protects the contents of the cell and helps control the materials that enter and leave.



Before Diffusion
There is a higher concentration of oxygen molecules outside the cell than inside the cell.

After Diffusion
The concentration of oxygen molecules is the same outside and inside the cell.

FIGURE 8
Diffusion in Action
Molecules move by diffusion from an area of higher concentration to an area of lower concentration.
Predicting *What would happen if the concentration of oxygen molecules outside the cell was lower than inside the cell?*

Diffusion of Oxygen Have you ever used a microscope to observe one-celled organisms in pond water? These organisms obtain the oxygen they need to survive from the water around them. Luckily for them, there are many more molecules of oxygen in the water outside the cell than there are inside the cell. In other words, there is a higher concentration of oxygen molecules in the water than inside the cell. Remember that the cell membrane is permeable to oxygen molecules. The oxygen molecules diffuse from the area of higher concentration—the pond water—through the cell membrane to the area of lower concentration—the inside of the cell.

Reading Checkpoint **By what process do small molecules move into cells?**

Osmosis
Like oxygen, water passes easily into and out of cells through the cell membrane. **Osmosis** is the diffusion of water molecules through a selectively permeable membrane. **Because cells cannot function properly without adequate water, many cellular processes depend on osmosis.**

Osmosis and Diffusion Remember that molecules tend to move from an area of higher concentration to an area of lower concentration. In osmosis, water molecules move by diffusion from an area where they are highly concentrated through the cell membrane to an area where they are less concentrated.

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Effects of Osmosis Osmosis can have important consequences for a cell. Look at Figure 9 to see the effect of osmosis on cells. In Figure 9A, a red blood cell is bathed in a solution in which the concentration of water is the same as it is inside the cell. This is the normal shape of a red blood cell.

Contrast this shape to the cell in Figure 9B. The red blood cell is floating in water that contains a large amount of salt. The concentration of water molecules outside the cell is lower than the concentration of water molecules inside the cell. This difference in concentration occurs because the salt takes up space in the salt water. Therefore, there are fewer water molecules in the salt water outside the cell compared to the water inside the cell. As a result, water moves out of the cell by osmosis. When water moves out, cells shrink.

In Figure 9C, the red blood cell is floating in water that contains a very small amount of salt. The water inside the cell contains more salt than the solution outside the cell. Thus, the concentration of water outside the cell is greater than it is inside the cell. The water moves into the cell, causing it to swell.

Reading Checkpoint **How is osmosis related to diffusion?**

Lab zone Try This Activity

Diffusion in Action

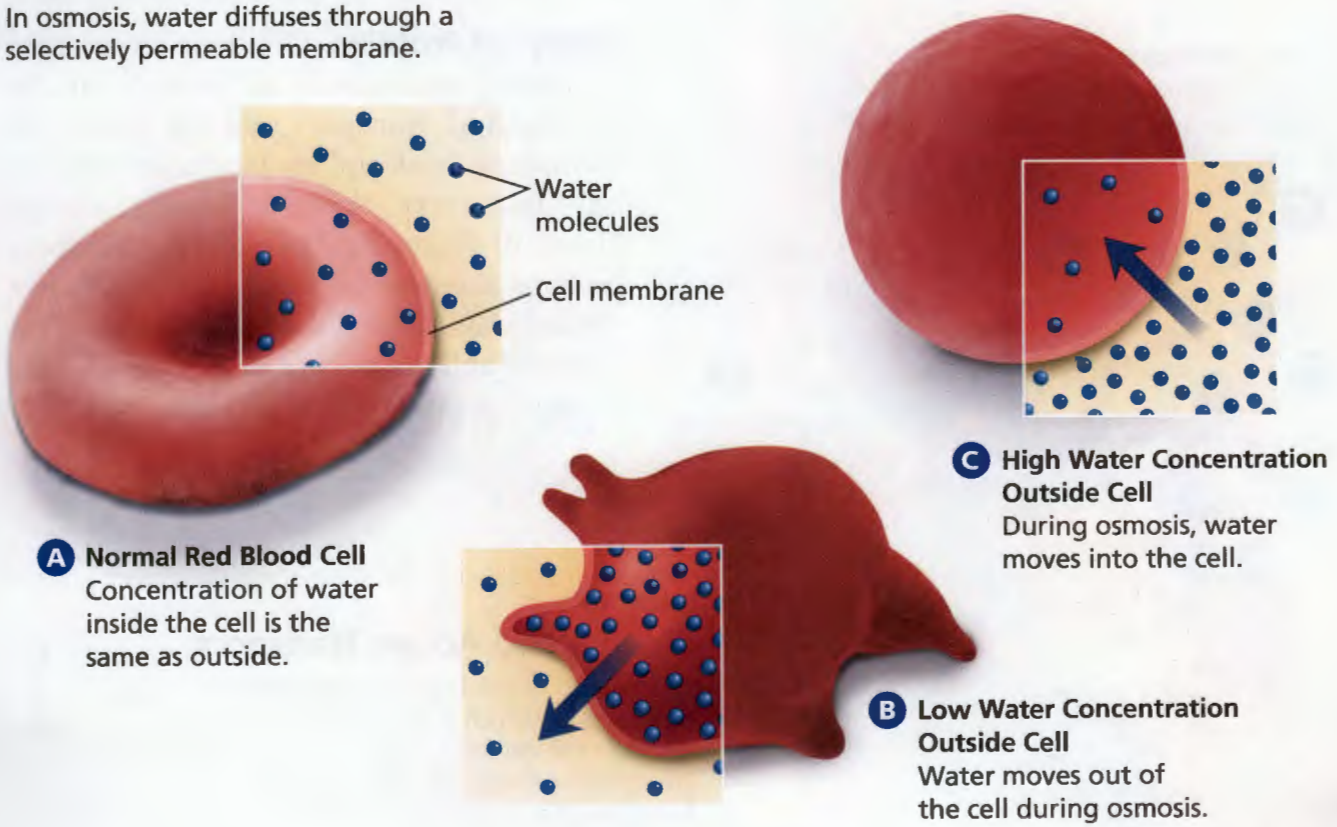
Here's how you can observe the effects of diffusion.

1. Fill a small, clear plastic cup with cold water. Place the cup on the table and allow it to sit until there is no movement in the water.
2. Use a plastic dropper to add one large drop of food coloring to the water.
3. Observe the water every minute. Note any changes that take place. Continue to observe until you can no longer see any changes.

Inferring What role did diffusion play in the changes you observed?

FIGURE 9
Effects of Osmosis on Cells

In osmosis, water diffuses through a selectively permeable membrane.



A Normal Red Blood Cell
Concentration of water inside the cell is the same as outside.

B Low Water Concentration Outside Cell
Water moves out of the cell during osmosis.

C High Water Concentration Outside Cell
During osmosis, water moves into the cell.

Active Transport

If you have ever ridden a bicycle down a long hill, you know that it doesn't take any of your energy to go fast. But you do have to use some of your energy to pedal back up the hill. For a cell, moving materials through the cell membrane by diffusion and osmosis is like cycling downhill. These processes do not require the cell to use its own energy. The movement of dissolved materials through a cell membrane without using cellular energy is called **passive transport.**

What if a cell needs to take in a substance that is present in a higher concentration inside the cell than outside? The cell would have to move the molecules in the opposite direction than they naturally move by diffusion. Cells can do this, but they have to use energy—just as you would use energy to pedal back up the hill. **Active transport** is the movement of materials through a cell membrane using cellular energy. **Active transport requires the cell to use its own energy, while passive transport does not.**

Transport Proteins Cells have several ways of moving materials by active transport. In one method, transport proteins in the cell membrane "pick up" molecules outside the cell and carry them in, using energy. Figure 10 illustrates this process. Transport proteins also carry molecules out of cells in a similar way. Some substances that are carried into and out of cells in this way include calcium, potassium, and sodium.

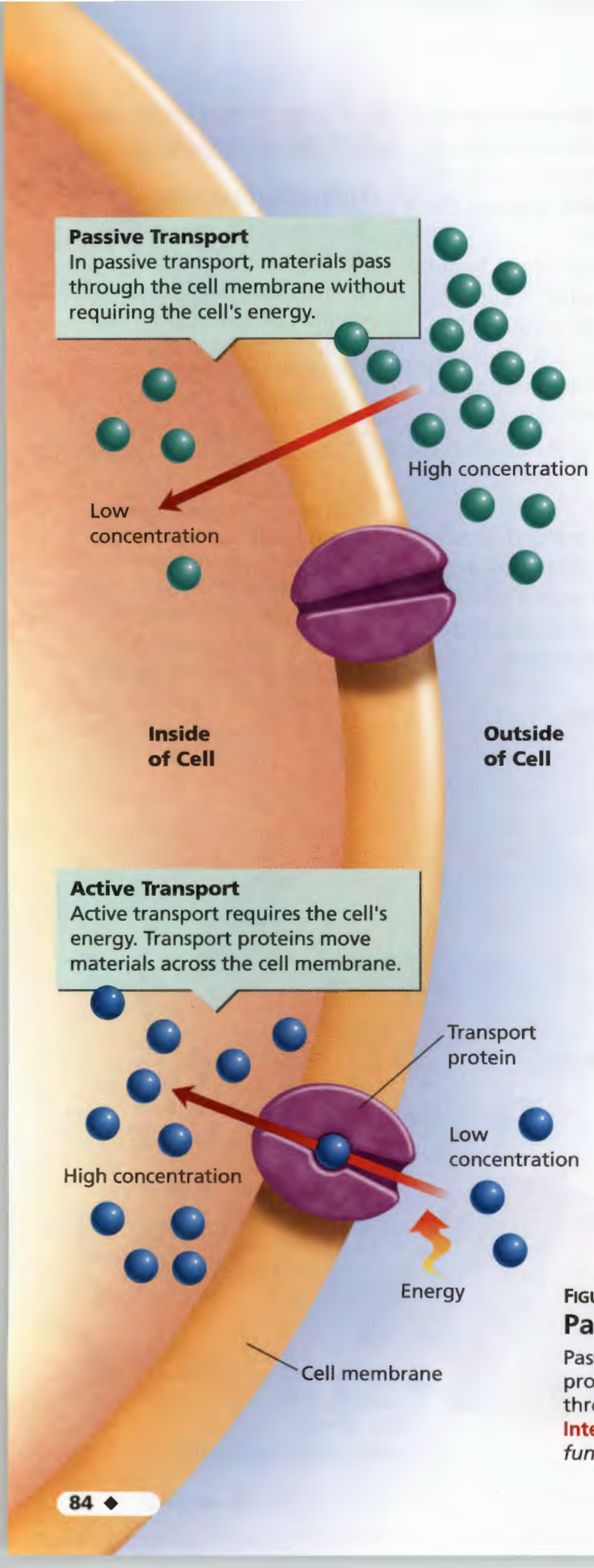


FIGURE 10
Passive and Active Transport
Passive and active transport are two processes by which materials pass through the cell membrane.
Interpreting Diagrams *What is the function of a transport protein?*

Transport by Engulfing Figure 11 shows another method of active transport. First, the cell membrane surrounds and engulfs, or encloses, a particle. Once the particle is engulfed, the cell membrane wraps around the particle and forms a vacuole within the cell. The cell must use energy in this process.

FIGURE 11
Amoeba Engulfing Food
This single-celled amoeba is surrounding a smaller organism. The amoeba will engulf the organism and use it for food. Engulfing is a form of active transport.

Why Cells Are Small As you know, most cells are so small that you cannot see them without a microscope. Have you ever wondered why cells are so small? One reason is related to how materials move into and out of cells.

As a cell's size increases, more of its cytoplasm is located farther from the cell membrane. Once a molecule enters a cell, it is carried to its destination by a stream of moving cytoplasm, somewhat like the way currents in the ocean move a raft. But in a very large cell, the streams of cytoplasm must travel farther to bring materials to all parts of the cell. It would take much longer for a molecule to reach the center of a very large cell than it would in a small cell. Likewise, it would take a long time for wastes to be removed. If a cell grew too large, it could not function well enough to survive.

Reading Checkpoint **What prevents cells from growing very large?**

Section 2 Assessment

Target Reading Skill **Building Vocabulary** Use your definitions to help answer the questions below.

Reviewing Key Concepts

1. a. **Defining** What is diffusion?
   b. **Relating Cause and Effect** Use diffusion to explain what happens when you drop a sugar cube into a mug of hot tea.
2. a. **Defining** What is osmosis?
   b. **Describing** Describe how water molecules move through the cell membrane during osmosis.
   c. **Applying Concepts** A selectively permeable membrane separates solutions A and B. The concentration of water molecules in Solution B is higher than that in Solution A. Describe how the water molecules will move.
3. a. **Comparing and Contrasting** How is active transport different from passive transport?
   b. **Reviewing** What are transport proteins?
   c. **Explaining** Explain why transport proteins require energy to function in active transport.

Math Practice

A scientist dissolves 60 g of sugar in 3 L of water.

4. **Calculating a Concentration** Calculate the concentration of the solution in grams per liter.
5. **Ratios** Express the concentration as a ratio.

Section 3

Photosynthesis

Reading Preview

Key Concepts

- How does the sun supply living things with the energy they need?
- What happens during the process of photosynthesis?

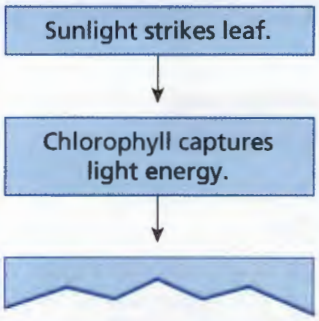
Key Terms

- photosynthesis
- autotroph
- heterotroph
- pigment
- chlorophyll
- stomata

Target Reading Skill

Sequencing A sequence is the order in which the steps in a process occur. As you read, create a flowchart that shows the steps in photosynthesis. Put each step in a separate box in the flowchart in the order in which it occurs.

Steps in Photosynthesis



Lab zone Discover Activity

Where Does the Energy Come From?

1. Obtain a solar-powered calculator that does not use batteries. Place the calculator in direct light.
2. Cover the solar cells with your finger. Note how your action affects the number display.
3. Uncover the solar cells. What happens to the number display?
4. Now cover all but one of the solar cells. How does that affect the number display?

Think It Over

Inferring From your observations, what can you infer about the energy that powers the calculator?

On a plain in Africa, dozens of zebras peacefully eat the grass. But watch out—the zebras' grazing will soon be harshly interrupted. A group of lions is about to attack the herd. The lions will kill one of the zebras and eat it.

Both the zebras and the lions use the food they eat to obtain energy. Every living thing needs energy. All cells need energy to carry out their functions, such as making proteins and transporting substances into and out of the cell. The zebra's meat supplies the lion's cells with the energy they need, just as the grass provides the zebra's cells with energy. But plants and certain other organisms, such as algae and some bacteria, obtain their energy in a different way. These organisms use the energy in sunlight to make their own food.

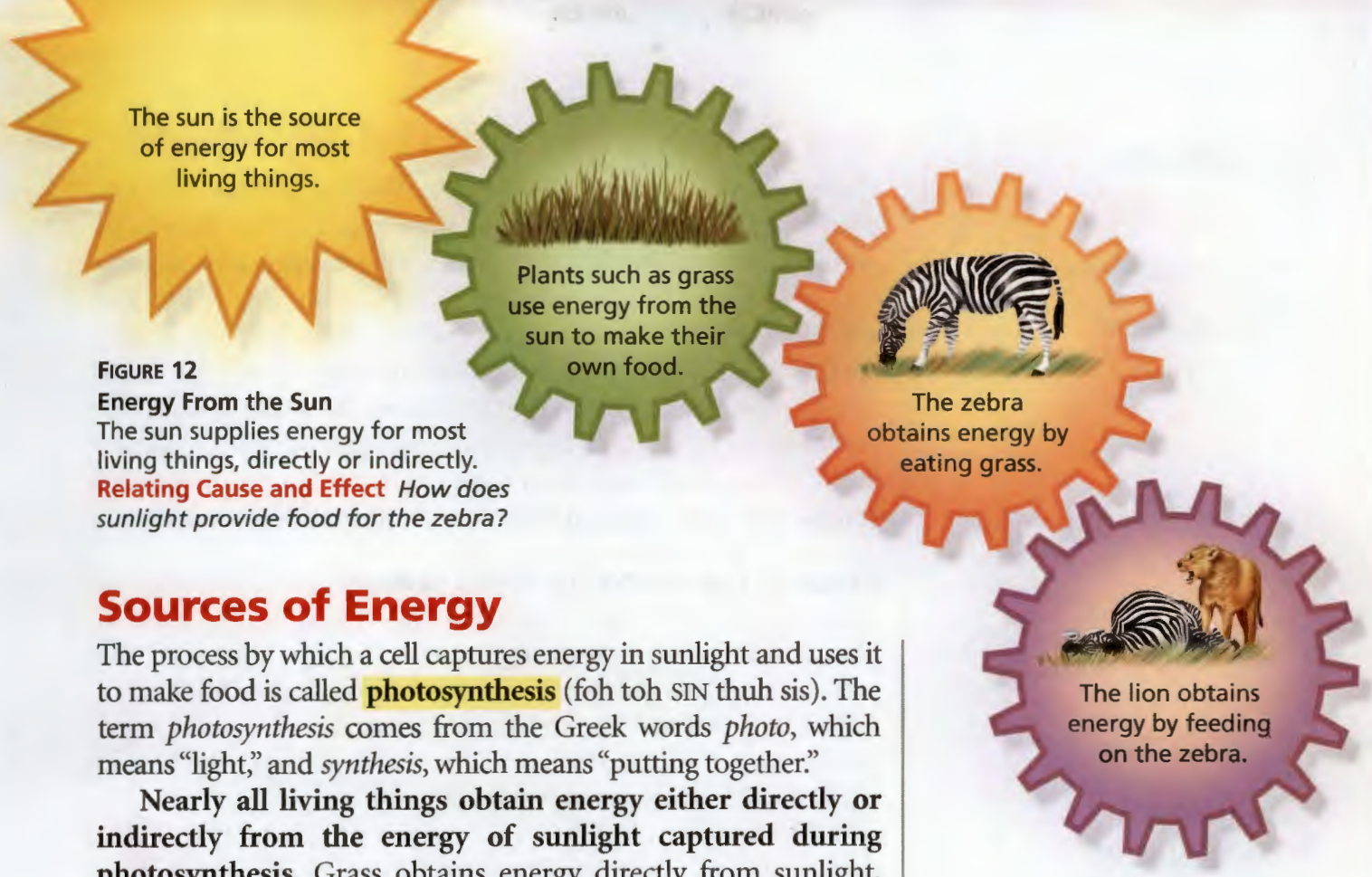


FIGURE 12
Energy From the Sun
The sun supplies energy for most living things, directly or indirectly.
Relating Cause and Effect *How does sunlight provide food for the zebra?*

Sources of Energy

The process by which a cell captures energy in sunlight and uses it to make food is called **photosynthesis** (foh toh SIN thuh sis). The term *photosynthesis* comes from the Greek words *photo*, which means "light," and *synthesis*, which means "putting together."

Nearly all living things obtain energy either directly or indirectly from the energy of sunlight captured during photosynthesis. Grass obtains energy directly from sunlight, because it makes its own food during photosynthesis. When the zebra eats the grass, it gets energy that has been stored in the grass. Similarly, the lion obtains energy stored in the zebra. The zebra and lion both obtain the sun's energy indirectly, from the energy that the grass obtained through photosynthesis.

Plants manufacture their own food through the process of photosynthesis. An organism that makes its own food is called an **autotroph** (AWT oh trahf). An organism that cannot make its own food, including animals such as the zebra and the lion, is called a **heterotroph** (HET ur oh trahf). Many heterotrophs obtain food by eating other organisms. Some heterotrophs, such as fungi, absorb their food from other organisms.

Reading Checkpoint **What are autotrophs?**

FIGURE 13
Autotrophs and Heterotrophs
Grass, which makes its own food during photosynthesis, is an autotroph. Zebras and lions are heterotrophs, because they cannot make their own food.

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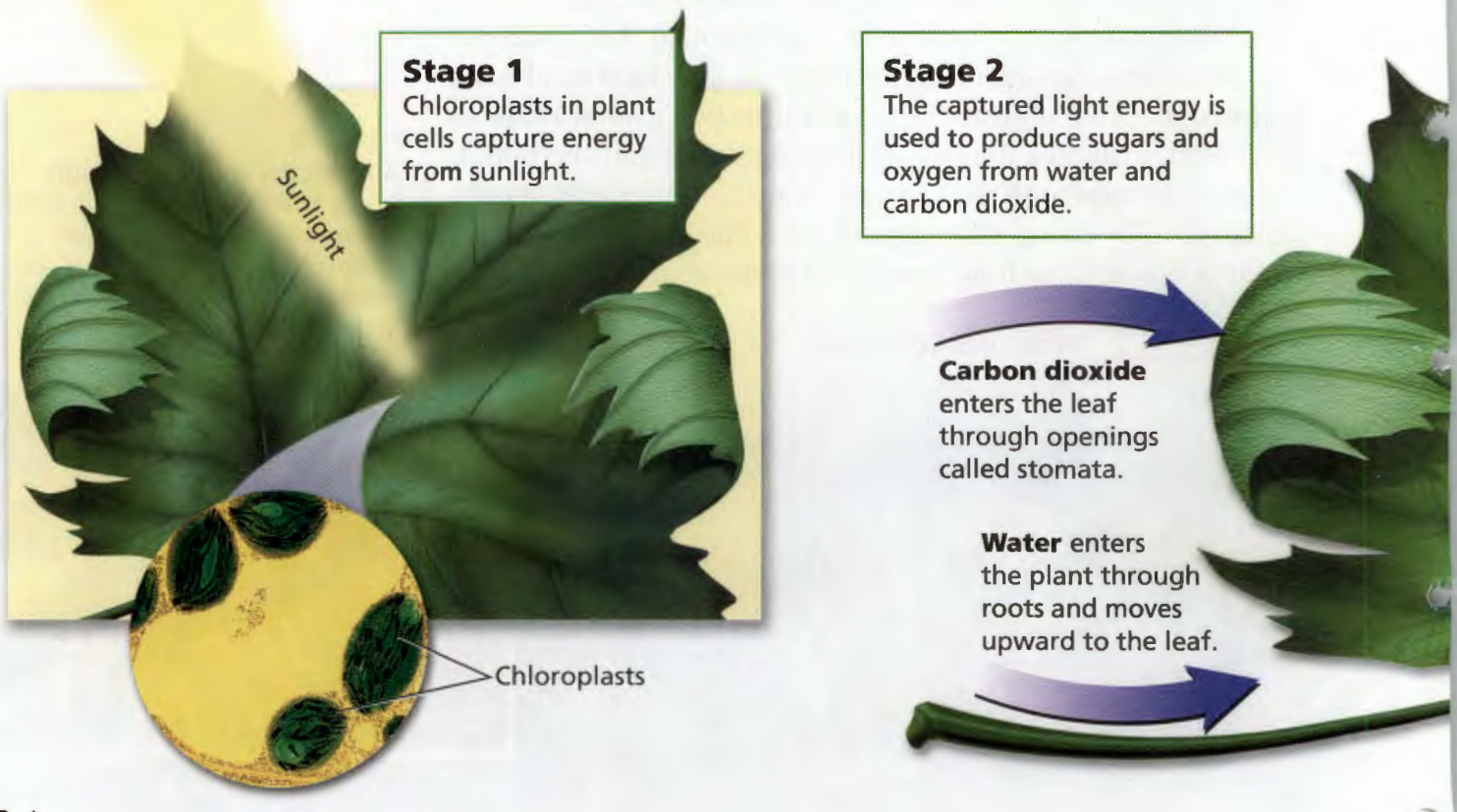
The Two Stages of Photosynthesis

Photosynthesis is a complex process. **During photosynthesis, plants and some other organisms use energy from the sun to convert carbon dioxide and water into oxygen and sugars.** The process of photosynthesis is shown in Figure 14. You can think of photosynthesis as taking place in two stages: capturing the sun's energy and producing sugars. You're probably familiar with many two-stage processes. To make a cake, for example, the first stage is to combine the ingredients to make the batter. The second stage is to bake the batter. To get the desired result—the cake—both stages must occur in the correct order.

Stage 1: Capturing the Sun's Energy The first stage of photosynthesis involves capturing the energy in sunlight. In plants, this energy-capturing process occurs mostly in the leaves. Recall that chloroplasts are green organelles inside plant cells. The green color comes from **pigments,** colored chemical compounds that absorb light. The main photosynthetic pigment in chloroplasts is **chlorophyll.**

Chlorophyll functions in a manner similar to that of the solar "cells" in a solar-powered calculator. Solar cells capture the energy in light and use it to power the calculator. Similarly, chlorophyll captures light energy and uses it to power the second stage of photosynthesis.

FIGURE 14
Two Stages of Photosynthesis
Photosynthesis has two stages, as shown in the diagram.
Interpreting Diagrams *Which stage requires light?*



Stage 2: Using Energy to Make Food In the next stage of photosynthesis, the cell uses the captured energy to produce sugars. The cell needs two raw materials for this stage: water (H_2O) and carbon dioxide (CO_2). In plants, the roots absorb water from the soil. The water then moves up through the plant's stem to the leaves. Carbon dioxide is one of the gases in the air. Carbon dioxide enters the plant through small openings on the undersides of the leaves called **stomata** (STOH muh tuh) (singular *stoma*). Once in the leaves, the water and carbon dioxide move into the chloroplasts.

Inside the chloroplasts, the water and carbon dioxide undergo a complex series of chemical reactions. The reactions are powered by the energy captured in the first stage. These reactions produce chemicals as products. One product is a sugar that has six carbon atoms. Six-carbon sugars have the chemical formula $C_6H_{12}O_6$. Recall that sugars are a type of carbohydrate. Cells can use the energy in the sugar to carry out important cell functions.

The other product of photosynthesis is oxygen (O_2), which exits the leaf through the stomata. In fact, almost all the oxygen in Earth's atmosphere was produced by living things through the process of photosynthesis.

Reading Checkpoint **What makes plants green?**

Lab zone Try This Activity

Looking at Pigments

You can observe the pigments in a leaf.

1. Cut a strip 5 cm by 20 cm out of a paper coffee filter.
2. Place a leaf on top of the paper strip, about 2 cm from the bottom.
3. Roll the edge of a dime over a section of the leaf, leaving a narrow band of color on the paper strip.
4. Pour rubbing alcohol into a plastic cup to a depth of 1 cm. Stand the paper strip in the cup so the color band is about 1 cm above the alcohol. Hook the other end of the strip over the top of the cup.
5. After 10 minutes, remove the paper strip and let it dry. Observe the strip.
6. Wash your hands.

Inferring What does the paper strip's appearance reveal about leaf pigments?

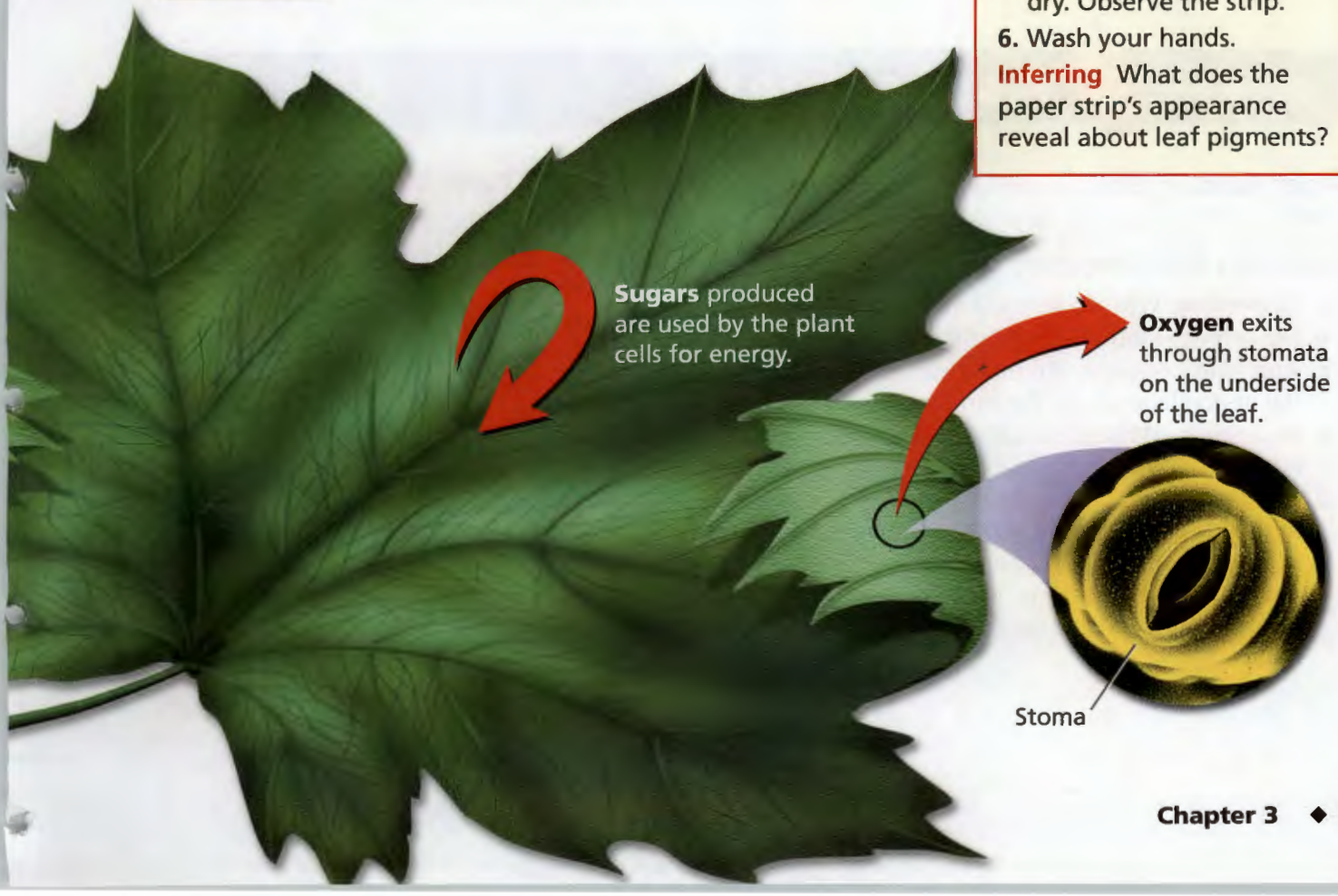


FIGURE 15 Stored Energy When you eat a carrot, you obtain energy stored during photosynthesis.

The Photosynthesis Equation The events of photosynthesis can be summed up by the following chemical equation:

$$\underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} \xrightarrow{\text{light energy}} \underset{\text{a sugar}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2}$$

Notice that the raw materials—six molecules of carbon dioxide and six molecules of water—are on the left side of the equation. The products—one molecule of a sugar and six molecules of oxygen—are on the right side of the equation. An arrow, which you can read as "yields," connects the raw materials to the products. Light energy, which is necessary for the chemical reaction to occur, is written above the arrow.

What happens to the sugar produced in photosynthesis? Plant cells use some of the sugar for food. The cells break down the sugar molecules to release the energy they contain. This energy can then be used to carry out the plant's functions. Some sugar molecules are converted into other compounds, such as cellulose. Other sugar molecules may be stored in the plant's cells for later use. When you eat food from plants, such as potatoes or carrots, you are eating the plant's stored energy.

Reading Checkpoint **In the photosynthesis equation, what does the arrow mean?**

Section 3 Assessment

Target Reading Skill **Sequencing** Use your definitions to help answer the questions.

Reviewing Key Concepts

1. a. **Reviewing** Why do living things need energy?
   b. **Explaining** How do plants obtain energy?
   c. **Applying Concepts** An insect eats a leaf. Explain how the insect depends on the sun for energy.
2. a. **Reviewing** What chemical equation sums up the events of photosynthesis?
   b. **Comparing and Contrasting** What are the substances needed for photosynthesis? What substances are produced during photosynthesis?
   c. **Making Generalizations** Would you expect a plant to produce more oxygen on a cloudy day or a sunny day? Explain.

Writing in Science

Job Qualifications When people apply for jobs, they often must complete a job application form in which they describe their qualifications for a job. Suppose that you are a leaf, and that you are applying for a job in a photosynthesis factory. Write a paragraph in which you summarize your qualifications for the job of photosynthesis. Your paragraph should include the following words: *chloroplasts, chlorophyll, light, energy, water, carbon dioxide,* and *stomata*.

Section 4

Respiration

Reading Preview

Key Concepts

- What events occur during respiration?
- What is fermentation?

Key Terms

- respiration
- fermentation

Target Reading Skill

Using Prior Knowledge Your prior knowledge is what you already know before you read about a topic. Before you read, write a definition of respiration in a graphic organizer like the one below. As you read, revise your definition based on what you learn.

What You Know
1. Definition of respiration:

What You Learned
1.

Lab zone **Discover Activity**

What Is a Product of Respiration?

1. Put on your goggles. Fill two test tubes half full of warm water. Add 5 mL of sugar to one of the test tubes. Put the tubes in a test-tube rack.
2. Add 0.5 mL of dried yeast (a single-celled organism) to each tube. Stir the contents of each tube with a straw. Place a stopper snugly in the top of each tube.
3. Observe the two test tubes over the next 10 to 15 minutes.

Think It Over

Observing How can you account for any changes you observed?

You've been hiking all morning, and you are hungry. You get out the sandwich you packed and begin munching. Why does your body need food?

What Is Respiration?

Food supplies your body with glucose, an energy-rich sugar. **Respiration** is the process by which cells obtain energy from glucose. **During respiration, cells break down simple food molecules such as sugar and release the energy they contain.**

Storing and Releasing Energy Energy stored in cells is something like money in a savings account. During photosynthesis, plants capture energy from sunlight and "save" it in the form of carbohydrates, including sugars and starches. Similarly, when you eat, you add to your body's energy savings account. When cells need energy, they "withdraw" it by breaking down the carbohydrates in the process of respiration.

Breathing and Respiration The term *respiration* has two meanings. You have probably used it to mean "breathing," that is, moving air in and out of your lungs. To avoid confusion, the respiration process that takes place inside cells is sometimes called cellular respiration. Breathing brings oxygen, which is usually necessary for cellular respiration, into your lungs.

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The Two Stages of Respiration Like photosynthesis, respiration is a two-stage process. The first stage takes place in the cytoplasm of the organism's cells. There, molecules of glucose are broken down into smaller molecules. Oxygen is not involved, and only a small amount of energy is released.

The second stage of respiration takes place in the mitochondria. There, the small molecules are broken down into even smaller molecules. These chemical reactions require oxygen, and they release a great deal of energy. This is why the mitochondria are sometimes called the "powerhouses" of the cell.

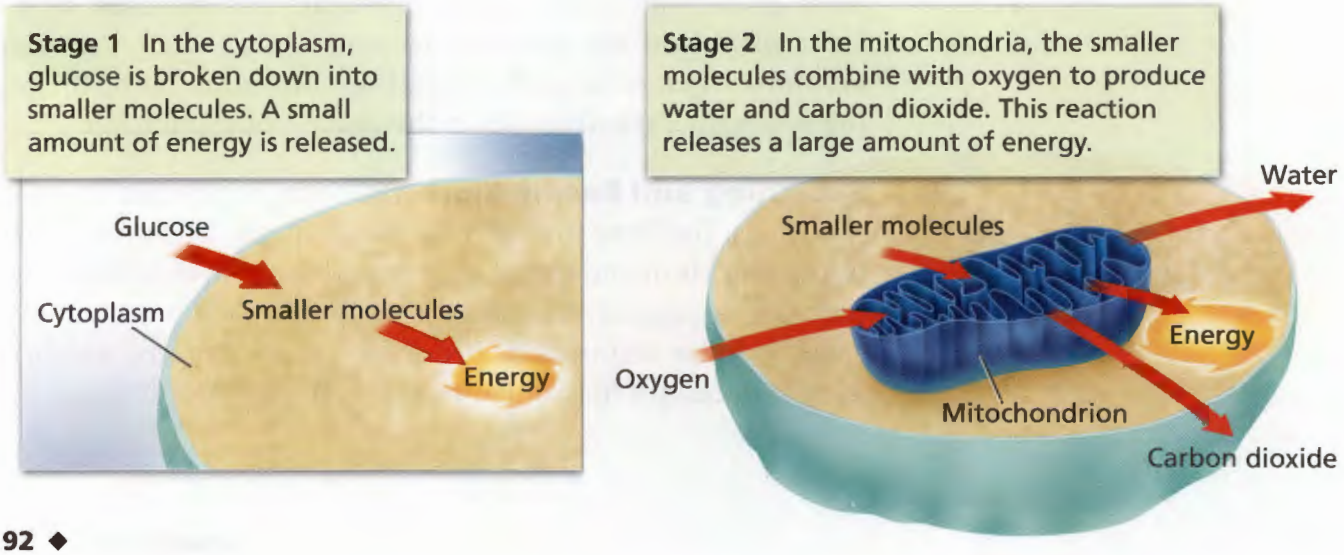
Trace the steps in the breakdown of glucose in Figure 16. Note that energy is released in both stages. Two other products of respiration are carbon dioxide and water. These products diffuse out of the cell. In most animals, the carbon dioxide and some water leave the body during exhalation, or breathing out. Thus, when you breathe in, you take in oxygen—a raw material for respiration. When you breathe out, you release carbon dioxide and water—products of respiration.

The Respiration Equation Although respiration occurs in a series of complex steps, the overall process can be summarized in the following equation:

$$\underset{\text{sugar}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2} \longrightarrow \underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} + \text{energy}$$

Notice that the raw materials for respiration are sugar and oxygen. Plants and other organisms that undergo photosynthesis make their own sugar. The glucose in the cells of animals and other organisms comes from the food they consume. The oxygen used in respiration comes from the air or water surrounding the organism.

FIGURE 16
Two Stages of Respiration
Respiration, like photosynthesis, takes place in two stages.
Interpreting Diagrams *In which stage is oxygen used?*



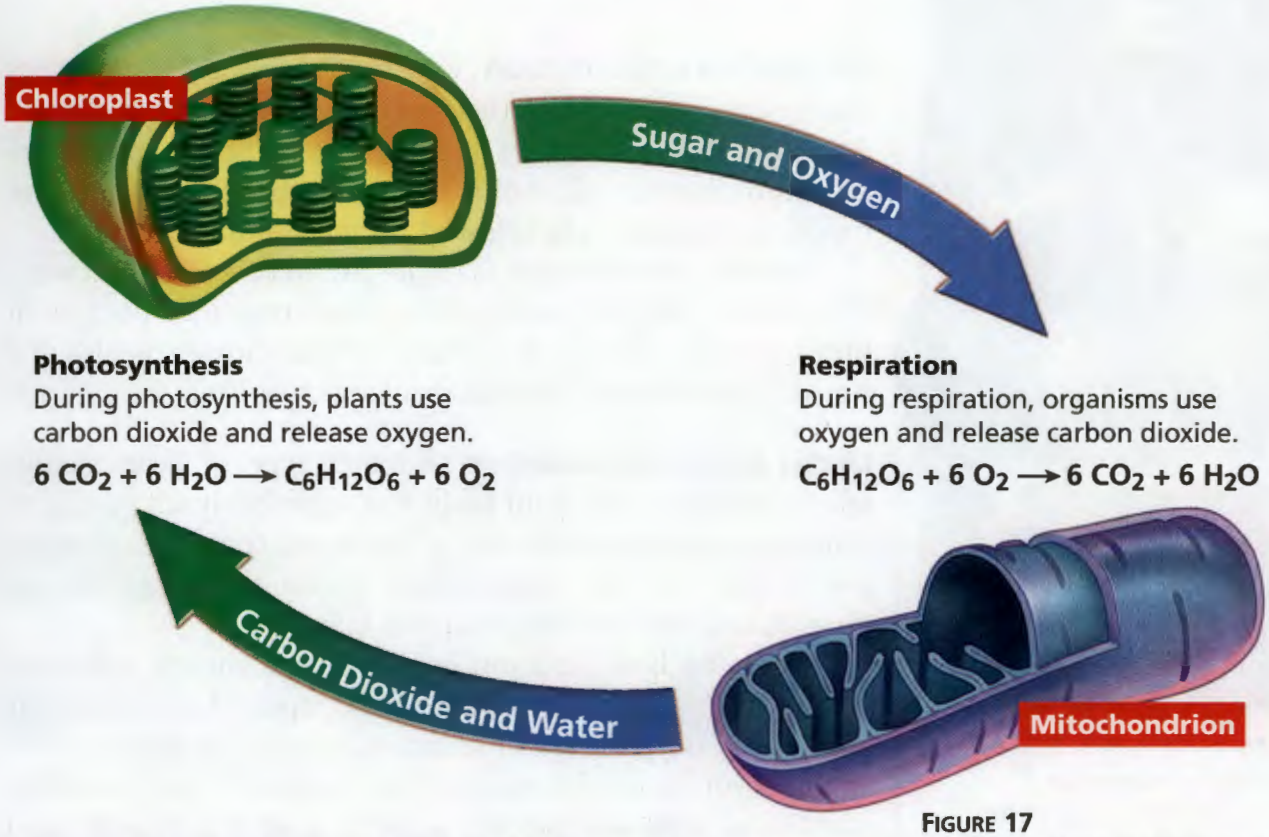


FIGURE 17
Photosynthesis and Respiration You can think of photosynthesis and respiration as opposite processes.
Comparing and Contrasting *Which process uses oxygen? Which uses carbon dioxide?*

Comparing Photosynthesis and Respiration Can you notice anything familiar about the equation for respiration? You are quite right if you said it is the opposite of the equation for photosynthesis. This is an important point. During photosynthesis, carbon dioxide and water are used to produce sugars and oxygen. During respiration, the sugar glucose and oxygen are used to produce carbon dioxide and water. Photosynthesis and respiration can be thought of as opposite processes.

Together, these two processes form a cycle that keeps the levels of oxygen and carbon dioxide fairly constant in Earth's atmosphere. As you can see in Figure 17, living things use both gases over and over again.

Reading Checkpoint **Which process—photosynthesis or respiration—produces water?**

Fermentation

Some cells are able to obtain energy from food without using oxygen. For example, some single-celled organisms live where there is no oxygen, such as deep in the ocean or in the mud of lakes or swamps. These organisms obtain their energy through **fermentation**, an energy-releasing process that does not require oxygen. **Fermentation provides energy for cells without using oxygen.** The amount of energy released from each sugar molecule during fermentation, however, is much lower than the amount released during respiration.

FIGURE 18
Lactic Acid Fermentation
When an athlete's muscles run out of oxygen, lactic acid fermentation supplies the cells with energy.

Alcoholic Fermentation One type of fermentation occurs when yeast and some other single-celled organisms break down sugars. This process is sometimes called alcoholic fermentation because alcohol is one of the products. The other products are carbon dioxide and a small amount of energy.

Alcoholic fermentation is important to bakers and brewers. The carbon dioxide produced by yeast creates air pockets in bread dough, causing it to rise. Carbon dioxide is also the source of bubbles in alcoholic drinks such as beer.

Lactic Acid Fermentation Another type of fermentation takes place at times in your body. You've probably felt its effects. Think of a time when you ran as fast as you could for as long as you could. Your leg muscles were pushing hard against the ground, and you were breathing quickly.

No matter how hard you breathed, your muscle cells used up the oxygen faster than it could be replaced. Because your cells lacked oxygen, fermentation occurred. The fermentation supplied your cells with energy. One product of this type of fermentation is an acid known as lactic acid. When lactic acid builds up, you feel a painful sensation in your muscles. Your muscles feel weak and sore.

Section 4 Assessment

Target Reading Skill

Using Prior Knowledge Review your graphic organizer about respiration. List two things that you learned about respiration.

Reviewing Key Concepts

1. a. **Reviewing** What happens during respiration?
   b. **Reviewing** What is the equation for respiration?
   c. **Comparing and Contrasting** Compare the equations for respiration and photosynthesis.
   d. **Relating Cause and Effect** Explain why cellular respiration adds carbon dioxide to the atmosphere, but photosynthesis does not.
2. a. **Identifying** What is the process in which cells obtain energy without using oxygen?
   b. **Inferring** How would athletes be affected if this process could not take place?
   c. **Predicting** Is this process more likely to occur during a short run or a long walk? Explain your answer.

Lab zone At-Home Activity

Make Bread With an adult family member, follow a recipe in a cookbook to make a loaf of bread using yeast. Explain to your family what causes the dough to rise. After you bake the bread, observe a slice and look for evidence that fermentation occurred.