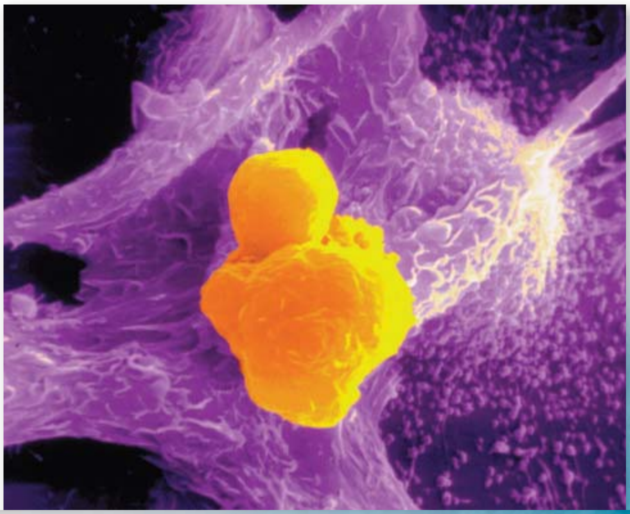
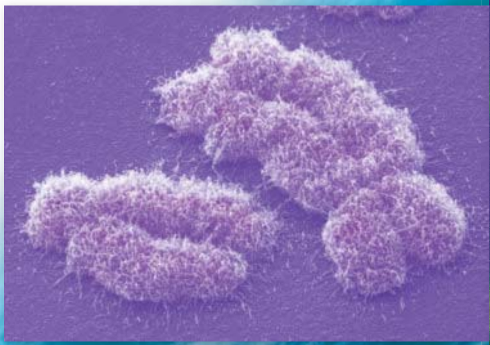
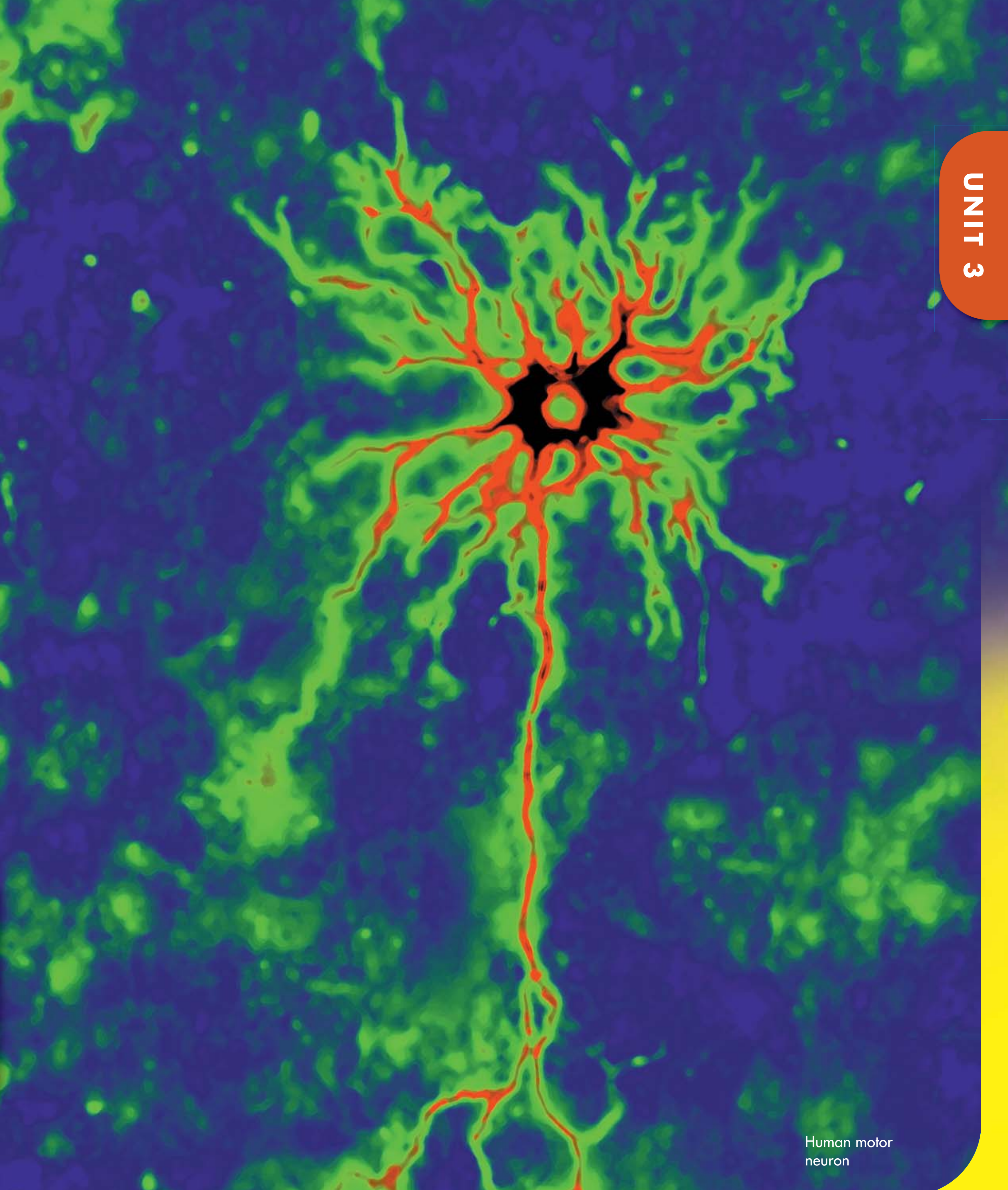
UNIT 3 Cells



Macrophage (purple) attack on a cancer cell (yellow)



Sex chromosomes of a human male: Y (left) and X (right)



Human motor neuron

DISCOVERIES IN SCIENCE

Cell Biology

1665

Robert Hooke builds a microscope to look at tiny objects. He discovers cells after observing a thin piece of cork under a microscope. He also finds cells in plants and fungi.

Hooke's microscope

1772

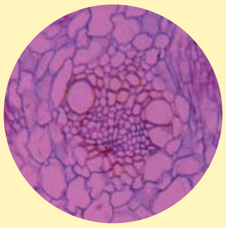
British clergyman and chemist, Joseph Priestly, presents his paper, *On Different Kinds of Air,* in which he describes his discovery of oxygen and other previously-unknown gases found in air. He also demonstrates that oxygen is produced by plants.

1839

Theodor Schwann shows that all animal tissue is made of cells. With plant biologist, Matthias Schleiden, Schwann identifies cell components, such as membranes and a nucleus common, to many eukaryotic cells.

1855

Rudolf Virchow publishes a theory stating that all cells come from another cells. He explains, "Where a cell exists, there must have been a preexisting cell."



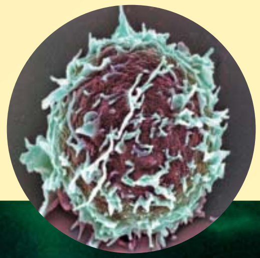
Animal cells

1945

Keith R. Porter, Albert Claude, and Ernest F. Fullam publish the first electromicrograph of a cell. Small organelles, such as the endoplasmic reticulum and the Golgi apparatus, are visible for the first time.

LATE 1950s

Canadian scientists Ernest McCulloch and James Till begin research on stem cells in rodents. Bone marrow stem cells can produce several types of blood cells.



Bone marrow stem cell

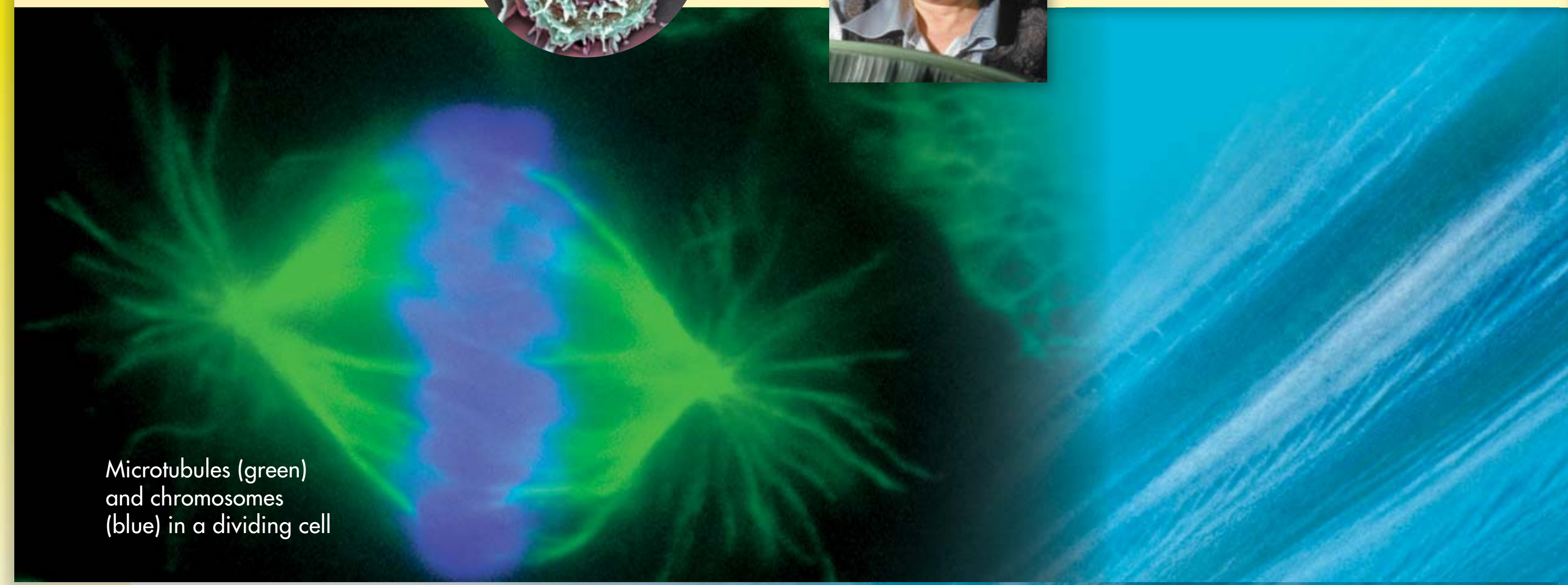
1971

Lynn Margulis proposes the endosymbiotic theory of the origins of cell organelles. This theory states that chloroplasts and mitochondria in eukaryotes evolved from prokaryotes.

Lynn Margulis

2004

Richard Axel, and Linda Buck earn the Noble Prize in Medicine or Physiology for their discovery of how olfactory cells detect odors and how the brain processes information to provide a sense of smell.



Microtubules (green) and chromosomes (blue) in a dividing cell

BIOLOGY CAREER

UNIT 3

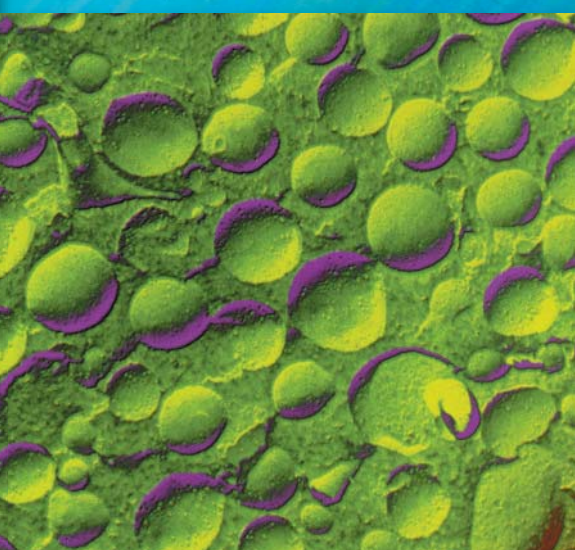
Cell Biologist

Shubha Govind

Shubha Govind is a professor of biology at City College, City University of New York. Govind considers her most important scientific contribution to be developing a model system for using genetic tools to study the molecular basis of host-parasite interaction in fruit flies. She is studying how blood cells of fruit flies are formed and how they guard against infections when flies are attacked by parasites. She is also studying how parasites have evolved to overcome the immune reactions of the fly.

Govind grew up in India, and her family traveled a lot. As she traveled, she was impressed with the diversity of flora and fauna in different parts of the country. By the time she reached middle school, she knew that she wanted to be a biologist.

Apart from science, Govind enjoys reading, listening to music and spending time with family and friends.



Freeze fracture of cell

Chapter Planner 9

Cellular Respiration and Photosynthesis

	Time	Standards	Teach Key Ideas
CHAPTER OPENER, pp. 194–195	15 min.	*National Science Education Standards*	
SECTION 1 Energy in Living Systems, pp. 197–201 ❯ Chemical Energy ❯ Metabolism and the Carbon Cycle ❯ Transferring Energy	45 min.	LSCell 5, LSMat 2, LSMat 3	**Bellringer Transparency** **Transparencies** B32 ATP Releases Energy • B34 Breakdown of Starch • B35 Photosynthesis-Cellular Respiration Cycle **Visual Concepts** Comparing Autotrophs and Heterotrophs • Comparing ADP and ATP • Linking Photosynthesis and Respiration
SECTION 2 Photosynthesis, pp. 202–207 ❯ Harvesting Light Energy ❯ Two Electron Transport Chains ❯ Producing Sugar ❯ Factors that Affect Photosynthesis	90 min.	LSCell 5, LSMat 2	**Bellringer Transparency** **Transparencies** B52 Photosynthesis • B25 Absorption Spectra of Photosynthesis Pigments • B24 Chloroplasts • B30 Summary of Processes in Light Reactions • B31 Calvin Cycle **Visual Concepts** Photosynthesis • Spectrum of Light and Plant Pigments • Chlorophyll a and b • Carotenoid • Parts of a Chloroplast • Electron Transport Chain • Energy Yield in Aerobic Respiration • Calvin Cycle • Environmental Influences on Photosynthesis
SECTION 3 Cellular Respiration, pp. 208–213 ❯ Glycolysis ❯ Aerobic Respiration ❯ Fermentation	90 min.	LSMat 3	**Bellringer Transparency** **Transparencies** B53 Cellular Respiration • B37 Glycolysis• B39 Krebs Cycle • B54 Electron Transport Chain of Aerobic Respiration **Visual Concepts** Cellular Respiration • Glycolysis • NAD and NADH • Krebs Cycle • FAD and $FADH_2$ • Fermentation

See also PowerPoint® Resources

Chapter Review and Assessment Resources

- SE Super Summary, p. 216
- SE Chapter Review, p. 217
- SE Standardized Test Prep, p. 219
- Review Resources
- Chapter Tests A and B
- go.hrw.com Holt Online Assessment

CHAPTER Fast Track *Thorough instruction will require the times shown.*

Basic Learners

- TE Comprehension Strategy, p. 198
- TE ATP Structure, p. 200
- TE Stages of Photosynthesis, p. 204
- TE NADPH, p. 205
- TE Role Playing, p. 206
- TE Relating Processes, p. 208
- TE Glycolysis, p. 209
- TE Electron Transport Chain, p. 211
- Directed Reading Worksheets*
- Active Reading Worksheets*
- Lab Manuals, Level A*
- Study Guide* ■

Advanced Learners

- TE Carotenoids, p. 203
- Critical Thinking Worksheets*
- Concept Mapping Worksheets*
- Science Skills Worksheets*
- Lab Datasheets, Level C*

Key

- **SE** Student Edition
- **TE** Teacher's Edition
- Chapter Resource File
- Workbook
- Transparency
- CD or CD-ROM
- * Datasheet or blackline master available
- ■ Also available in Spanish

All resources listed below are also available on the Teacher's One-Stop Planner.

Why It Matters	Hands-On	Skills Development	Assessment
Build student motivation with resources about high-interest applications.	**SE** **Inquiry Lab** Stored Energy, p. 195* ■	**TE** **Reading Toolbox** Assessing Prior Knowledge, p. 194 **SE** **Reading Toolbox,** p. 196	
TE **Demonstration** Forms of Energy, p. 197 **TE** **Food Energy,** p. 199	**SE** **Quick Lab** Product of Photosynthesis, p. 198* ■ **Exploration Lab** Plant and Animal Interrelationships*	**TE** **Math Skills** Balancing Equations, p. 199 **SE** **Reading Toolbox** Key-Term Fold, p. 200 **TE** **Reading Toolbox** Key-Term Fold, p. 200	**SE** **Section Review** **TE** **Formative Assessment** **Spanish Assessment*** ■ **Section Quiz** ■
TE **Demonstration** Products of Photosynthesis, p. 202 **TE** **Demonstration** The Thylakoid Model, p. 203 **TE** **Increasing Levels of Carbon Dioxide,** p. 206	**SE** **Quick Lab** Photosynthetic Rate, p. 205* ■	**TE** **Science Skills** Spectroscopy, p. 203 **SE** **Reading Toolbox** Describing Space, p. 205 **TE** **Reading Toolbox** Describing Space, p. 205	**SE** **Section Review** **TE** **Formative Assessment** **Spanish Assessment*** ■ **Section Quiz** ■
TE **Life Without Oxygen,** p. 209 **TE** **Cyanide,** p. 212 **SE** **Life in a Biosphere,** p. 214	**SE** **Skills Practice Lab** Cellular Respiration, p. 215* ■ **Inquiry Lab** Conditions That Favor Cellular Respiration*	**SE** **Reading Toolbox** Pattern Puzzles, p. 211 **TE** **Reading Toolbox** Pattern Puzzles, p. 211 **TE** **Math Skills** ATP Molecules, p. 211	**SE** **Section Review** **TE** **Formative Assessment** **Spanish Assessment*** ■ **Section Quiz** ■

See also Lab Generator

See also Holt Online Assessment Resources

Resources for Differentiated Instruction

English Learners

- **TE** Autotrophs and Heterotrophs, p. 198
- **TE** Fermentation, p. 212
- Directed Reading Worksheets*
- Active Reading Worksheets*
- Lab Manuals, Level A*
- Study Guide* ■
- Note-taking Workbook*
- Multilingual Glossary

Struggling Readers

- **TE** Comprehension Strategy, p. 198
- **TE** Electron Transport Chain, p. 211
- Directed Reading Worksheets*
- Active Reading Worksheets*
- Lab Manuals, Level A*
- Study Guide*
- Note-taking Workbook*
- Special Needs Activities and Modified Tests*

Special Education Students

- **TE** ATP Structure, p. 200
- **TE** NADPH, p. 205
- Directed Reading Worksheets*
- Active Reading Worksheets*
- Lab Manuals, Level A*
- Study Guide* ■
- Note-taking Workbook*
- Special Needs Activities and Modified Tests*

Alternative Assessment

- **TE** Calvin Cycle, p. 206
- Science Skills Worksheets*
- Section Quizzes* ■
- Chapter Tests A, B, and C* ■

Chapter 9

Overview

The purpose of this chapter is to examine how energy is made available to cells to power metabolism. Students will learn how energy is captured and stored during photosynthesis in autotrophs, and how that energy becomes usable to both autotrophs and heterotrophs through cellular respiration.

READING TOOLBOX

Assessing Prior Knowledge Students should understand the following concepts:

- the roles of autotrophs and heterotrophs in the food chain
- transformation of energy and matter

Visual Literacy Ask students to describe how energy is being obtained by the organisms in the photo. (The plant leaf obtains energy from the sun; the caterpillar obtains energy by eating the leaf.) Which organism uses photosynthesis to obtain energy? (the plant)

Chapter 9 Photosynthesis and Cellular Respiration

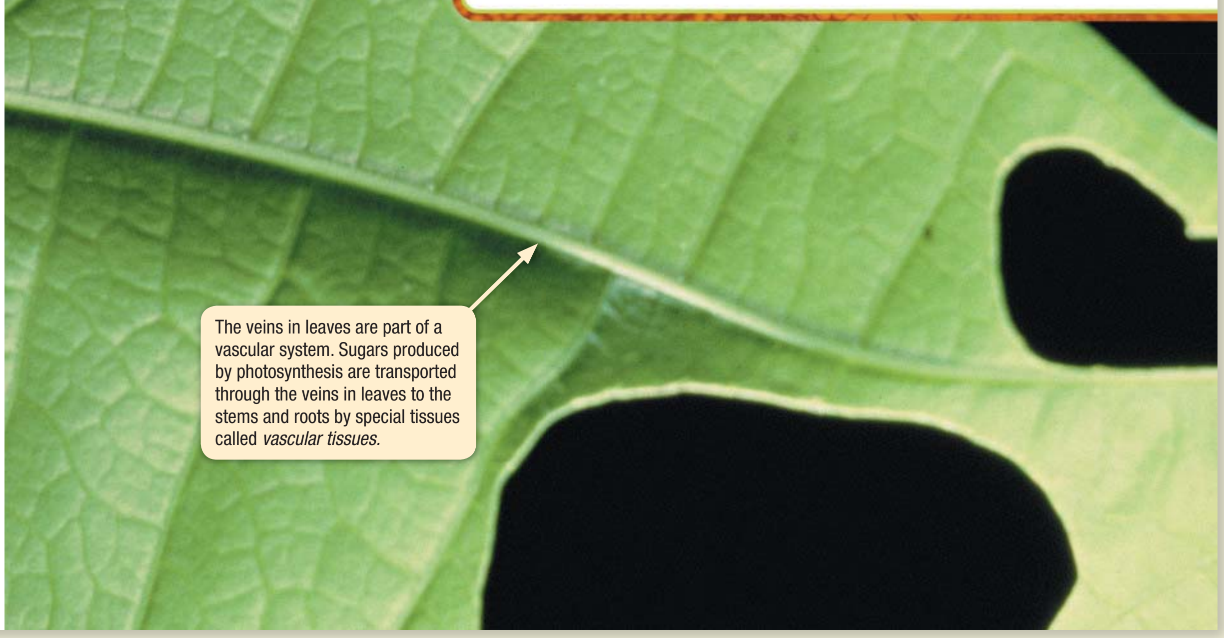
Preview

Why It Matters

Everything you do—from moving, to breathing, to thinking—requires energy. The energy your body uses is mostly derived from the processes of photosynthesis and cellular respiration.

A saturniid caterpillar feeds on a leaf. The leaf provides the energy the caterpillar needs to grow and undergo metamorphosis.

Chapter Correlations	National Science Education Standards
LSCell 1	Cells have particular structures that underlie their functions.
LSCell 2	Most cell functions involve chemical reaction.
LSCell 4	Cell functions are regulated.
LSCell 5	Plant cells contain chloroplasts, the site of photosynthesis.
LSMat 2	The energy for life primarily derives from the sun.
LSMat 3	The chemical bonds of food molecules contain energy.



InquiryLab

15 min

Stored Energy

Have you ever used a hot pack? The way the hot pack works has to do with energy storage and the release of stored heat energy during a chemical reaction.

Procedure

1. Fill a **plastic foam cup** halfway with **tap water.**
2. Measure and record the water's temperature.
3. Examine the **reusable hot pack.** Then, activate it according to your instructor's directions. Quickly place the pack into the water-filled cup.
4. Measure and record the water's temperature at intervals of 30 s.

Analysis

1. **Describe** what happened when the hot pack was activated.
2. **Explain** how the activated hot pack affected the temperature of the water.
3. **Explain** where the observed heat energy came from.
4. **Speculate** whether the hot pack can be restored to its activated state by placing the hot pack in direct sunlight.

The veins in leaves are part of a vascular system. Sugars produced by photosynthesis are transported through the veins in leaves to the stems and roots by special tissues called *vascular tissues.*

InquiryLab

Teacher's Notes Remind students that the energy transfer they observe can be traced back to the sun. To "restore" the pack with energy, it must be placed in a boiling water solution or microwave oven. Read the directions to insure that you are following the correct procedure. The boiling water was heated by either an electric or fossil fuel–dependent device. Students should trace both electricity generation and the formation of fossil fuels to their initial solar source.

Materials
- hot pack
- plastic foam cup
- thermometer

Safety: Remind students that glassware is easily broken. Caution students to be careful when handling the activated hot pack.

Answers to Analysis

1. The liquid crystallized.
2. The water temperature increased.
3. The heat energy was stored in the initial liquid state of the chemical. When it changed to a crystal, this heat was released.
4. No, it can't. You need a more concentrated energy source to restore the pack.

Key Resources

Interactive Tutor

READING TOOLBOX

Using Words

Check students' Key-Term Folds to see that they correctly followed the directions.

Using Language

1. in chloroplasts
2. in cell mitochondria

Using Graphic Organizers

The steps in the correct order are as follows:

breakdown of glucose
production of NADH
production of pyruvate

READING TOOLBOX

These reading tools can help you learn the material in this chapter. For more information on how to use these and other tools, see **Appendix: Reading and Study Skills.**

Using Words

Key-Term Fold A key-term fold is useful for studying definitions of key terms in a chapter. Each tab can contain a key term on one side and its definition on the other side.

Your Turn Make a key-term fold for the terms in this chapter.

1. Fold a sheet of lined notebook paper in half from left to right.
2. Using scissors, cut along every third line from the right edge of the paper to the center fold to make tabs.

Using Language

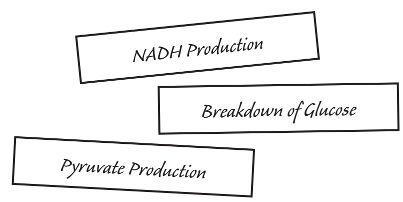
Describing Space As you read the chapter, look for language clues that answer the question, "Where does this process take place?" Words such as *inside, outside,* and *between* can help you learn where these processes happen. Knowing where these processes take place can help you better understand them.

Your Turn Describe as precisely as you can where the following processes happen.

1. photosynthesis
2. cellular respiration

Using Graphic Organizers

Pattern Puzzles You can use pattern puzzles to help you remember information. Exchanging puzzles with a classmate can help you study.



Your Turn Make pattern puzzles for the steps of glycolysis.

1. Write down the steps of the process. On a sheet of notebook paper, write down one step per line. Do not number the steps.
2. Cut the sheet of paper into strips with only one step per strip of paper. Shuffle the paper strips so that they are out of sequence.
3. Place the strips in the correct sequence. Confirm the order of the steps of the process by checking your text or class notes.

Section 1

Energy in Living Systems

Key Ideas	Key Terms	Why It Matters
What type of energy is used in cells, and what is the ultimate source of this energy? How is an organism's metabolism related to the carbon cycle? How is energy released in a cell?	photosynthesis cellular respiration ATP ATP synthase electron transport chain	Plants convert sunlight into chemical energy. This chemical energy can be used for biological processes in nearly all living things.

Imagine an abandoned house that is falling apart. The house, like almost everything else in the universe, breaks down over time. Restoring order to the house would require an input of energy, such as the energy needed to apply a fresh coat of paint. Living things also need energy in order to stay in good repair, or maintain their *homeostasis.* Remember that homeostasis is the process of maintaining internal order and balance even when the environment changes. Every organism must maintain homeostasis as long as it lives. Therefore, organisms require a constant source of energy.

Chemical Energy

Organisms use and store energy in the chemical bonds of organic compounds. Almost all of the energy in organic compounds comes from the sun. Solar energy enters living systems when plants, algae, and certain prokaryotes use sunlight to make organic compounds from carbon dioxide and water through the process of **photosynthesis.** Organisms that are able to perform photosynthesis, such as the wheat plants shown in **Figure 1,** are *autotrophs.* Autotrophs make organic compounds that serve as food for them and for almost all of the other organisms on Earth.

photosynthesis the process by which plants, algae, and some bacteria use sunlight, carbon dioxide, and water to produce carbohydrates and oxygen

Most autotrophs have a supply of food as long as sunlight is available. But how do other organisms get food molecules? To survive, organisms that cannot make their own food must absorb food molecules made by autotrophs, eat autotrophs, or eat organisms that consume autotrophs. Food molecules that are made or consumed by an organism are the fuel for its cells. Cells use these molecules to release the energy stored in the molecules' bonds. The energy is used to carry out life processes.

Reading Check *Why do organisms need a constant supply of energy? (See the Appendix for answers to Reading Checks.)*

Figure 1 Food crops such as wheat supply humans and other animals with the chemical energy needed to carry out life processes.

Section 1

Focus

This section is a broad overview of energy flow in natural systems. It also serves as an introduction to the process that converts food into ATP.

Bellringer

Use the Bellringer transparency to prepare students for this section.

Teach

Demonstration

Forms of Energy Ask students to look around the classroom and identify as many forms of energy being used as they can. (Answers will vary, but students should identify some forms of heat, light, chemical energy, mechanical energy, and electrical energy.) LS **Visual**

Teaching Key Ideas

Sandwich Energy Have students trace the energy in a ham and cheese sandwich back to the sun. (Ham ⟶ pig ⟶ grains ⟶ sun; cheese ⟶ milk ⟶ cow ⟶ grass ⟶ sun; bread ⟶ wheat ⟶ sun).

Key Resources

Transparencies
B32 ATP Releases Energy
B34 Breakdown of Starch
B35 Photosynthesis-Cellular Respiration Cycle

Visual Concepts
Comparing Autotrophs and Heterotrophs
Comparing ADP and ATP
Linking Photosynthesis and Respiration

Teach, *continued*

QuickLab

Teacher's Notes Elodea can be found at some pet stores and most stores that sell aquarium fish. A 0.25 percent solution of baking soda can be made by dissolving 0.25 g of baking soda in 100 mL of water. Students may need to practice placing the test tube over the inverted funnel. First, fill the test tube with the solution. Place your thumb over the opening tightly so no air can get in. Submerge your thumb and the mouth of the test tube under water. Once the mouth of the test tube is underwater, you can release your thumb and maneuver the test tube over the stem of the funnel. Be sure you have the elodea in place under the funnel before you begin.

Safety Cautions Remind students that glassware is easily broken. Remind students to not eat any part of a plant used in the lab and to wash their hands thoroughly after handling any part of a plant.

Materials
- 0.25% baking-soda-and-water solution, 500 mL
- beaker, 600 mL
- elodea sprigs, 20-cm long (2–3)
- glass funnel
- test tube
- protective gloves

Answers to Analysis
1. The level of the solution in the test tube went down as gas (oxygen) displaced the liquid.
2. The snail would use some of the oxygen generated by the plant.

Hands-On

QuickLab

MULTI-DAY 15 min

Product of Photosynthesis

Plants use photosynthesis to produce food. One product of photosynthesis is oxygen. In this activity, you will observe the process of photosynthesis in elodea.

Procedure
1. Add **450 mL of baking-soda-and-water solution** to a **beaker.**
2. Put **two or three sprigs of elodea** into the beaker. The baking soda will provide the elodea with the carbon dioxide it needs for photosynthesis.
3. Place the wide end of a **glass funnel** over the elodea. The elodea and the funnel should be completely submerged in the solution.
4. Fill a **test tube** with the remaining solution. Place your thumb over the end of the test tube. Turn the test tube upside down, taking care that no air enters. Hold the opening of the test tube under the solution, and place the test tube over the small end of the funnel.
5. Place the beaker setup in a well-lit area near a lamp or in direct sunlight, and leave it overnight.

Analysis
1. **Describe** what happened to the solution in the test tube.
2. CRITICAL THINKING **Predicting Patterns** Explain what may happen if an animal, such as a snail, were put into the beaker with the elodea sprig.

Metabolism and the Carbon Cycle

Metabolism involves either using energy to build organic molecules or breaking down organic molecules in which energy is stored. Organic molecules contain carbon. Therefore, an organism's metabolism is part of Earth's carbon cycle. The carbon cycle not only makes carbon compounds continuously available in an ecosystem but also delivers chemical energy to organisms living within that ecosystem.

Photosynthesis Energy enters an ecosystem when organisms use sunlight during photosynthesis to convert stable carbon dioxide molecules into glucose, a less stable carbon compound. In plant cells and algae, photosynthesis takes place in chloroplasts. **Figure 2** summarizes the process by which energy from the sun is converted to chemical energy in chloroplasts.

Cellular Respiration Organisms extract energy stored in glucose molecules. Through the process of **cellular respiration,** cells make the carbon in glucose into stable carbon dioxide molecules and produce energy. Thus, stable and less stable compounds alternate during the carbon cycle and provide a continuous supply of energy for life processes in an ecosystem.

The breakdown of glucose during cellular respiration is summarized in **Figure 2.** The inputs are a glucose molecule and six oxygen molecules. The final products are six carbon dioxide molecules and six water molecules. Energy is also released and used to make **ATP** (adenosine triphosphate), an organic molecule that is the main energy source for cell processes.

cellular respiration the process by which cells produce energy from carbohydrates

ATP adenosine triphosphate, an organic molecule that acts as the main energy source for cell processes; composed of a nitrogenous base, a sugar, and three phosphate groups

Reading Check *How is solar energy related to the carbon cycle?*

Differentiated Instruction

English Learners
Autotrophs and Heterotrophs Have students use a dictionary to define the root words of *autotroph* and *heterotroph.* (*auto* means "self;" *hetero* means "other;" *troph* means "nutrition or feeding;" an *autotroph* is literally "self-feeding," and a *heterotroph* is literally "other-feeding") LS **Verbal**

Basic Learners/Struggling Readers
Comprehension Strategy To help students comprehend the text on this page, use **Figure 2.** As they read each sentence under the headings *Photosynthesis* and *Cellular Respiration,* have them find the part of Figure 2 that the text is describing. For example, the sun shining on the watermelon and the arrow showing the reaction of CO_2 and H_2O to form glucose is described by the first sentence under *Photosynthesis.*
LS **Verbal/Visual**

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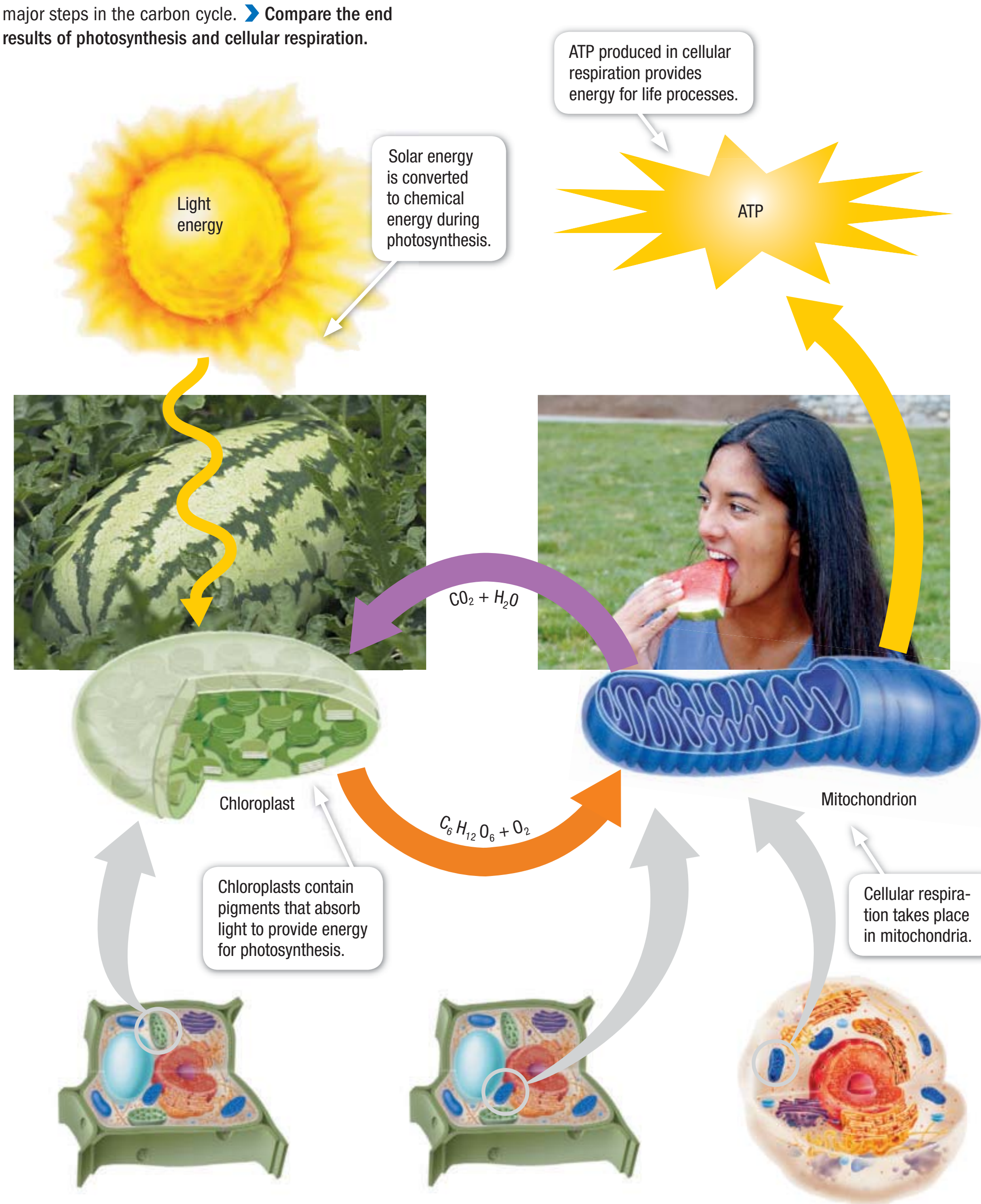
interact online
Keyword: HX8PHRF2

Photosynthesis and Cellular Respiration

Figure 2 Photosynthesis and cellular respiration are major steps in the carbon cycle. **Compare the end results of photosynthesis and cellular respiration.**



go.hrw.com
interact online

Students can interact with the cycle for "Photosynthesis and Cellular Respiration" by going to go.hrw.com and typing in the keyword HX8PHRF2.

Teaching Key Ideas

Understanding the Flow of Carbon in the Carbon Cycle Review **Figure 2** with students and ask them to summarize how carbon flows in cellular respiration and photosynthesis. (Carbon is taken in as carbon dioxide by plants in photosynthesis and converted to glucose. Glucose is broken down in mitochondria, producing carbon dioxide and energy.) **LS Visual**

Math Skills

Balancing Equations Write the equation $CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$ on the board and explain that it is the equation for photosynthesis that produces glucose. Ask the students to balance the equation. ($6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$) Ask them why equations need to be balanced. (Reactions satisfy the Law of Conservation of Mass. A balanced equation symbolizes mass conservation.) **LS Logical**

Answers to Caption Questions

Figure 2: Both processes convert carbon compounds into different carbon compounds. Photosynthesis works to store energy in a carbon compound, and cellular respiration works to release energy from a carbon compound.

Why It Matters

Food Energy Sometimes food is literally burned for energy. For years, grain has been fermented to make ethanol, an alcohol that can be added to gasoline to boost power and reduce pollution. New research is producing fuels based entirely on renewable sources. These fuels can be made from grains, such as corn and wheat, or even from trees and grasses. Biodiesel is a diesel-like fuel made from vegetable oil.

MISCONCEPTION ALERT

Plant Respiration Many students believe that plants undergo photosynthesis while other organisms undergo respiration. Point out that the reason plants undergo photosynthesis is to produce organic compounds that the plants can then use in respiration. Remind students that plant cells contain both chloroplasts and mitochondria. The mitochondria use the organic compounds to make ATP, which powers cellular activities.

Teach, continued

READING TOOLBOX

Key-Term Fold **photosynthesis** plants use light energy and CO_2 to make glucose
cellular respiration organisms break down glucose to make ATP
ATP energy "currency" for the cell
ATP synthase catalyzes synthesis of ATP
electron transport chain molecules that pump H^+ across membranes within the mitochondria

Transferring Energy

In chemical reactions, energy can be absorbed and released during the breaking and forming of bonds. For example, when a log burns, the energy stored in wood molecules is released in a burst of heat and light. **In cells, chemical energy is gradually released in a series of chemical reactions that are assisted by enzymes.** Recall that enzymes are proteins that act as catalysts in biochemical reactions.

ATP When cells break down food molecules, some of the energy in the molecules is released as heat. Cells use much of the remaining energy to make ATP. When glucose is broken down during cellular respiration, energy is stored temporarily in molecules of ATP. ATP can be used to power chemical reactions, such as those that build molecules. Paper money is portable and can be earned in one place and spent in another. Like money, ATP is a portable form of energy "currency" inside cells. ATP can be "earned," or made, in one place and "spent," or used, in another place. For example, ATP can be used to contract a muscle cell, to actively transport protein, or to help make more ATP.

ATP is a nucleotide made up of a chain of three phosphate groups. This chain is unstable because the phosphate groups are negatively charged and thus repel each other. When the bond of the third phosphate group is broken, energy is released. This produces adenosine diphosphate, or ADP. The equation below summarizes the process.

$$\text{ATP} \longrightarrow \text{ADP} + \text{P} + \text{energy}$$

The reaction in which ATP is converted to ADP requires a small input of energy. But much more energy is released than is used during the reaction.

Reading Check *How is ATP used inside a cell?*

READING TOOLBOX

Key-Term Fold On the back of your key-term fold, write a definition in your own words for each key term in this section.

ACADEMIC VOCABULARY

process a set of steps, events, or changes

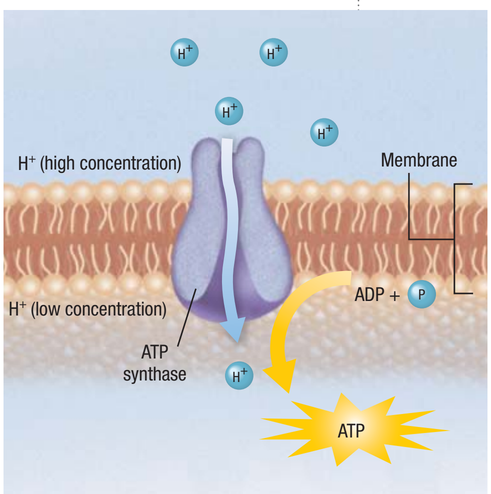


Figure 3 The energy of falling water can turn a water wheel, which provides energy to do work. In ATP synthase, the movement of hydrogen ions provides energy to convert ADP to ATP.

MISCONCEPTION ALERT

ATP Energy Because ATP supplies most of the energy that drives metabolism, ATP is sometimes called an energy-rich compound, and the bonds between its phosphate groups are sometimes called "high-energy" bonds. These terms are misleading because they imply that ATP contains an unusually large amount of energy. ATP serves as the cell's energy currency. The bonds between phosphate groups are unstable and therefore break easily. When they break, energy is released that can be used to drive metabolic processes.

Differentiated Instruction

Basic Learners/Special Education Students

ATP Structure Have students build a three-dimensional model of ATP (adenosine triphosphate). Students should use everyday materials and include the three phosphate groups, the sugar, and the base. Visually-impaired students can use well-designed models to learn the structure and role of ATP in respiration. Make sure students understand which part of the nucleotide is removed to release energy for cellular reactions. (the last phosphate group)
LS Visual/Kinesthetic

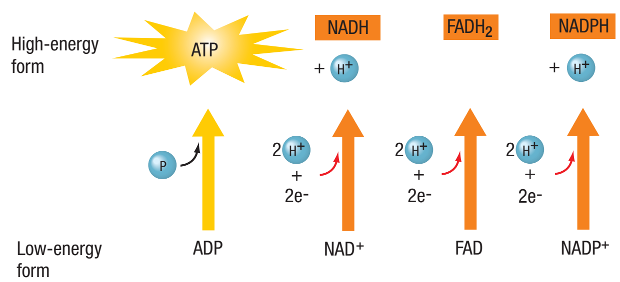


Figure 4 Electron carriers store energy by bonding with hydrogen, just as ATP stores energy by bonding a third phosphate group. **❯ Where is the electron transport chain found in animal cells?**

ATP Synthase In many cells, **ATP synthase,** an enzyme that catalyzes the synthesis of ATP, recycles ADP by bonding a third phosphate group to the molecule. As **Figure 3** shows, ATP synthase acts as both an enzyme and a carrier protein for hydrogen (H^+) ions. The flow of H^+ ions through ATP synthase powers the production of ATP. You can think of the H^+ ions moving through ATP synthase to produce ATP as falling water turning a water wheel to produce power. As H^+ ions flow, ATP synthase catalyzes a reaction in which a phosphate group is added to a molecule of ADP to make ATP.

Hydrogen Ion Pumps Recall how diffusion across cell membranes works. Particles of a substance diffuse through a membrane from a region of higher concentration to a region of lower concentration. The inner mitochondrial membrane allows H^+ ions to diffuse through only ATP synthase. When glucose is broken down during cellular respiration, NAD^+ (nicotinamide adenine dinucleotide) accepts electrons and hydrogen ions, which changes NAD^+ to NADH. As **Figure 4** shows, NADH enters an **electron transport chain,** a series of molecules in the inner membrane of a mitochondrion. The electron transport chain allows electrons to drop in energy as they are passed along and uses the energy released to pump H^+ ions out of a mitochondrion's inner compartment. This action increases the concentration of H^+ ions in the outer compartment. The ions then diffuse back into the inner compartment through ATP synthase.

ATP synthase an enzyme that catalyzes the synthesis of ATP

electron transport chain a series of molecules, found in the inner membranes of mitochondria and chloroplasts, through which electrons pass in a process that causes protons to build up on one side of the membrane

SciLINKS.
www.scilinks.org
Topic: ATP
Code: HX80123

Section 1 Review

❯ KEY IDEAS

1. **Identify** the primary source of energy that flows through most living systems.
2. **Explain** how an organism's metabolism is related to Earth's carbon cycle.
3. **Describe** how energy is released from ATP.

CRITICAL THINKING

4. **Analyzing Patterns** Explain how life involves a continuous flow of energy.
5. **Inferring Relationships** How can the energy in the food that a fox eats be traced back to the sun?
6. **Summarizing Information** What is the difference between cellular respiration and the process by which energy is released from a burning log?

WRITING FOR SCIENCE

7. **Career Connection** Research the educational background that a person needs to become an enzymologist. List the courses required, and describe additional degrees or training that are recommended for this career. Write a report on your findings.

Answers to Caption Questions

Figure 4: the inner membranes of mitochondria

Teaching Key Ideas

Recycling ATP ATP and ADP cycle constantly in the cell. Reusing the molecules is convenient because it does not require the cell to keep making all new molecules. In addition, the ADP molecule contains a small amount of energy that can be used for some functions by the cell without converting it to ATP. Most cell functions still require ATP, though.

❯ Close

Formative Assessment

Which of the following organisms is most likely an autotroph?

A. a sponge (Incorrect. The habitat of a sponge is such that it is not likely to be a photosynthetic organism.)
B. a Venus flytrap (Correct! Although a Venus flytrap traps insects for some nutrients, it still obtains energy from the sun.)
C. a worm (Incorrect. A worm is a heterotroph.)
D. a mushroom (Incorrect. A mushroom does not obtain energy through photosynthesis.)

Answers to Section Review

1. sunlight
2. Metabolism involves either using energy to build organic molecules or breaking down organic molecules in which energy is stored. Organic molecules contain carbon. Therefore, an organism's metabolism is part of Earth's carbon cycle.
3. When ATP reacts to form ADP, energy is released.
4. The flow of energy between organisms is continuous because energy passes from the sun to autotrophs and then to other organisms.
5. Foxes eat other organisms to get the energy needed for their metabolism. The animals they eat acquired their energy from eating plants. The plants used the energy of the sun to convert carbon dioxide into carbohydrates, which power their metabolism. Thus, foxes get their energy indirectly from the sun.
6. During cellular respiration, stored chemical energy is released gradually in a series of enzyme-assisted reactions. When a log is burned, stored chemical energy is released quickly as heat and light.
7. Answers will vary. Enzymologists study the structure and function of enzymes and the effects of enzyme deficiencies. The career requires a bachelor's and advanced degrees in chemistry or biology. Employers include universities and companies such as chemical and pharmaceutical manufacturers.

Section 2

Focus

This section describes the major events of the three stages of photosynthesis. These include the capture of energy (stage 1), the conversion of light energy to chemical energy (stage 2), and the formation of organic compounds using stored chemical energy (stage 3).

Bellringer

Use the Bellringer transparency to prepare students for this section.

Teach

Demonstration

Products of Photosynthesis Use a scalpel to make thin cross sections of a potato. Use a projection microscope to show the potato section, or have students examine the potato under a compound microscope. Ask them to look for starch granules, which should appear as large, translucent structures inside the potato cells. Adding iodine stain will make the starch granules more visible. Explain that much of the mass of the organic compounds plants make during photosynthesis is stored as starch. **LS Visual**

Answers to Caption Questions

Figure 5: inside chloroplasts

Section 2

Photosynthesis

Key Ideas	Key Terms	Why It Matters
› What is the role of pigments in photosynthesis? › What are the roles of the electron transport chains? › How do plants make sugars and store extra unused energy? › What are three environmental factors that affect photosynthesis?	thylakoid pigment chlorophyll Calvin cycle	Nearly all of the energy for life processes comes from the sun and is stored in organic molecules during the process of photosynthesis.

Plants, algae, and certain prokaryotes capture about 1% of the energy in the sunlight that reaches Earth and convert it to chemical energy through photosynthesis. Photosynthesis is the process that provides energy for almost all life.

Harvesting Light Energy

The cells of many photosynthetic organisms have chloroplasts, organelles that convert light energy into chemical energy. Study the diagram of a chloroplast in **Figure 5.**

A chloroplast has an outer membrane and an inner membrane. Molecules diffuse easily through the outer membrane. The inner membrane is much more selective about what substances enter and leave. Both membranes allow light to pass through.

The space inside the inner membrane is the stroma. Within the stroma is a membrane called the *thylakoid membrane.* This membrane is folded in a way that produces flat, disc-like sacs called **thylakoids.** These sacs, which contain molecules that absorb light energy for photosynthesis, are arranged in stacks. The first stage of photosynthesis begins when light waves hit these stacks.

› **Reading Check** *Describe the structure of a chloroplast.*

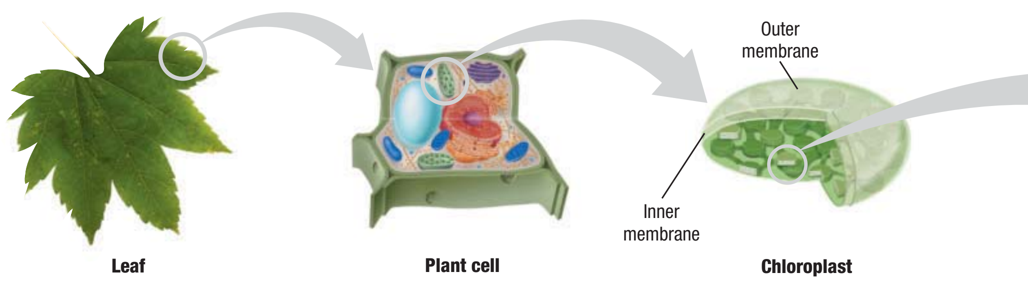


Figure 5 Pigments, as well as other molecules that participate in photosynthesis, are embedded in thylakoids. › **Where are thylakoids located?**

Key Resources

Transparencies
- B52 Photosynthesis
- B25 Absorption Spectra of Photosynthesis Pigments
- B24 Chloroplasts
- B30 Summary of Processes in Light Reactions
- B31 Calvin Cycle

Visual Concepts
- Photosynthesis
- Spectrum of light and Plant Pigments
- Chlorophyll a and b
- Carotenoid
- Parts of a Chloroplast
- Electron Transport Chain
- Energy Yield in Aerobic Respiration
- Calvin Cycle
- Environmental Influences on Photosynthesis

Electromagnetic Radiation Light is a form of electromagnetic radiation, energy that can travel through empty space in the form of waves. Radio waves, X-rays, and microwaves are also forms of electromagnetic radiation. The difference between these forms of radiation is that they have different wavelengths. Each wavelength corresponds to a certain amount of energy. The wavelength is the distance between consecutive wave peaks. Sunlight contains all of the wavelengths of visible light. You see these wavelengths as different colors.

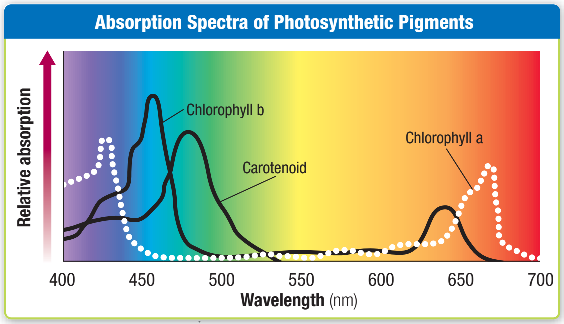


Figure 6 This graph shows the colors of light that three different pigments absorb. Where a curve peaks, much of the light at that wavelength is absorbed. Where a curve dips, much of the light at that wavelength is reflected or transmitted.

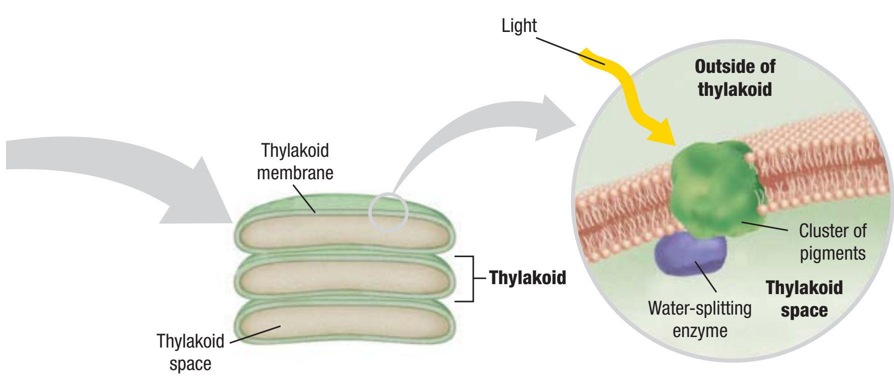
Pigments What makes the human eye sensitive to light? Cells in the back of the eye contain pigments. A **pigment** is a substance that absorbs certain wavelengths (colors) of light and commonly reflects all of the others. **In plants, light energy is harvested by pigments that are located in the thylakoid membrane of chloroplasts.** **Chlorophyll** is a green pigment in chloroplasts that absorbs light energy to start photosynthesis. It absorbs mostly blue and red light and reflects green and yellow light, which makes plants appear green. Plants have two types of chlorophyll: chlorophyll *a* and chlorophyll *b.* Plants also have pigments called *carotenoids*. Carotenoids absorb blue and green light, and they reflect yellow, orange, and red light. When chlorophyll fades away in the fall, the colors of carotenoids are exposed. Carotenoids aid photosynthesis by allowing plants to absorb additional light energy. **Figure 6** shows the wavelengths of light that are absorbed by chlorophyll *a,* chlorophyll *b,* and carotenoids—the pigments found in thylakoid membranes.

Electron Carriers When light hits a thylakoid, energy is absorbed by many pigment molecules. They all funnel the energy to a special chlorophyll molecule in a region called the *reaction center,* where the energy causes the electrons to become "excited" and to move to a higher energy level. These electrons are transferred quickly to other nearby molecules and then to an electron carrier.

thylakoid (THIE luh KOYD) a membrane system found within chloroplasts that contains the components for photosynthesis

pigment a substance that gives another substance or a mixture its color

chlorophyll (KLAWR uh FIL) a green pigment that is present in most plant and algae cells and some bacteria, that gives plants their characteristic green color, and that absorbs light to provide energy for photosynthesis



Teaching Key Concepts

Light Reflected and Absorbed Students will probably need to be refreshed in the fundamentals of color. An object reflects the colors you see. What colors do plant pigments absorb? (red, blue, and green) What colors are reflected? (yellow, orange, green, and red) What colors are absorbed and reflected? (red and green) **LS Visual**

Science Skills

Spectroscopy Many areas of biology use spectroscopy. The ability of a pigment to absorb various wavelengths of light is measured using the spectrophotometer. A graph plotting the pigment's light absorption versus wavelength is called an absorption spectrum, as shown in **Figure 6.**

Demonstration

Thylakoid Model Use small chocolate-covered mints (about 5 cm diameter) with white-creme centers. Make stacks of four or five mints. On one or two of the stacks, cut the top mint in half to expose the center before putting it on the stack. Point out that each stack of mints represents a column of thylakoids. To make the model more realistic, connect the stacks using strips of paper to represent the membranous connections between thylakoids. Ask students why it is more advantageous for the thylakoids to be in a stack than in a single unit. (Stacks increase the surface area available for light absorption by pigment molecules.) **LS Visual**

Differentiated Instruction

Advanced Learners/GATE

Carotenoids Yellow and orange vegetables are rich sources of carotenoids. A carotenoid called beta-carotene is an important dietary source of vitamin A, which is necessary for proper eyesight, for maintaining the health of membranes, and for tooth and bone development. Have students research and write a report on the effectiveness of beta-carotene as an antioxidant. Also have them compare the effectiveness of food sources of beta-carotene with that of other sources, such as dietary supplements. **LS Verbal**

Teach, *continued*

Teaching Key Ideas

Electron Transport Chain Guide students through the electron transport chains of photosynthesis shown in **Figure 7** by asking the following questions: "What is the source of the excited electrons?" (chlorophyll molecules) "What is the source of some of the replacement electrons?" (split water molecules) "What type of transport occurs when hydrogen ions are pumped into the thylakoid?" (active transport) "What type of transport occurs when hydrogen ions move out of the thylakoid?" (passive transport) "What kind of membrane protein is involved?" (carrier protein) Have students record the questions and answers in their notebooks. **LS Visual**

Answers to Caption Questions

Figure 7: The concentration of H^+ ions is greater inside the thylakoid than outside the thylakoid (ions move down the concentration gradient).

go.hrw.com
interact online

Students can interact with the "Electron Transport Chains of Photosynthesis" by going to go.hrw.com and typing in the keyword HX8PHRF7.

SCILINKS.
www.scilinks.org
Topic: Photosynthesis
Code: HX81140

Figure 7 Photosynthesis converts light energy to chemical energy. This figure shows key molecules involved in the capture of light, electron transport, and synthesis of ATP and NADPH. **What causes H^+ ions to move through the carrier protein that produces ATP?**

Two Electron Transport Chains

Electrons from the electron carrier are used to produce new molecules, including ATP, that temporarily store chemical energy. The carrier transfers the electrons to the first of two electron transport chains in the thylakoid membrane. Trace the path taken by the electrons in the electron transport chains shown in **Figure 7.** **During photosynthesis, one electron transport chain provides energy to make ATP, while the other provides energy to make NADPH.** Both chains use energy from electrons excited by light.

Producing ATP In mitochondria, electron transport chains pump H^+ ions through a membrane, which produces a concentration gradient. This process also happens in chloroplasts.

Step 1 Water Splitting The excited electrons that leave chlorophyll molecules must be replaced by other electrons. Plants get these replacement electrons from water molecules, H_2O. During photosynthesis, an enzyme splits water molecules inside the thylakoid. When water molecules are split, chlorophyll molecules take the electrons from the hydrogen atoms, H, which leaves H^+ ions. The remaining oxygen atoms, O, from the split water molecules combine to form oxygen gas, O_2. This oxygen gas is not used for any later steps of photosynthesis, so it is released into the atmosphere.

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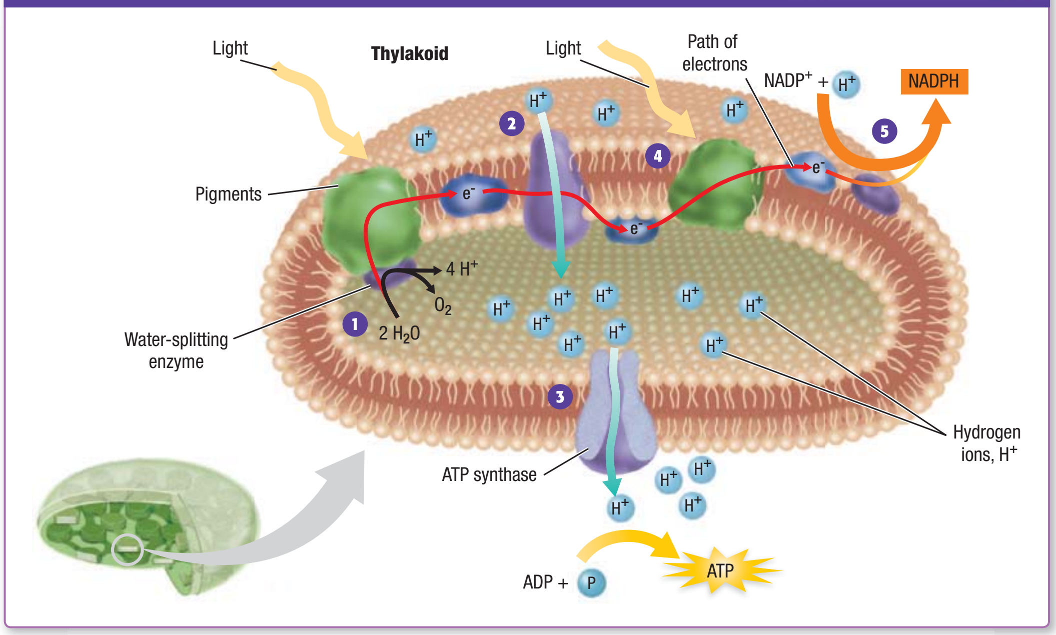
Keyword: HX8PHRF7

Electron Transport Chains of Photosynthesis



MISCONCEPTION ALERT

Why Plants Look Green Many people think that plants are green because plants use green light during photosynthesis. In fact, plants use very little green light, and instead use mainly red and blue light. Tell students that plants look green because they contain chlorophyll, which reflects green and yellow light while absorbing red and blue light.

Differentiated Instruction

Basic Learners

Stages of Photosynthesis Help students remember the three stages of photosynthesis by having them make flash cards with a structure or process on one side and a description of its role on the other side. Topics should include the names of the pigment molecules, thylakoids, electron transport chains, ATP, and NADPH. **LS Visual**

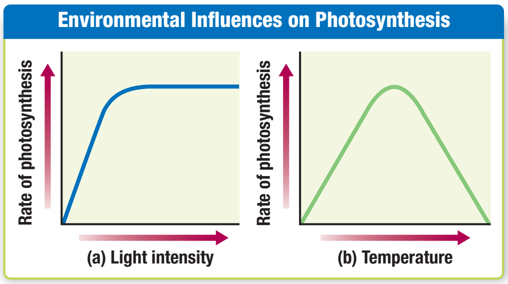
Data

QuickLab

15 min

Photosynthetic Rate

Changes in a plant's surroundings influence photosynthetic rate. The two graphs illustrate how photosynthetic rate responds to changes in light intensity and temperature. Use the graphs to answer the following questions.



Analysis

1. **Describe** how increasing light intensity affects the rate of photosynthesis.
2. **Explain** whether continuing to increase light intensity will increase the rate of photosynthesis.
3. **Describe** how increasing temperature affects the rate of photosynthesis.
4. CRITICAL THINKING **Inferring Relationships** Explain how a global temperature increase could affect plants.

Step 2 Hydrogen Ion Pump A protein acts as a membrane pump. Excited electrons transfer some of their energy to pump H^+ ions into the thylakoid. This process creates a concentration gradient across the thylakoid membrane.

Step 3 ATP Synthase The energy from the diffusion of H^+ ions through the carrier protein is used to make ATP. These carrier proteins are unusual because they function both as an ion channel and as the enzyme ATP synthase. As hydrogen ions pass through the channel portion of the protein, ATP synthase catalyzes a reaction in which a phosphate group is added to a molecule of ADP. The result of the reaction is ATP, which is used to power the final stage of photosynthesis.

Producing NADPH While one electron transport chain provides energy used to make ATP, a second electron transport chain receives excited electrons from a chlorophyll molecule and uses them to make NADPH. The second electron transport chain is to the right of the second cluster of pigment molecules in **Figure 7.**

Step 4 Reenergizing In this second chain, light excites electrons in the chlorophyll molecule. The excited electrons are passed on to the second chain. They are replaced by the de-energized electrons from the first transport chain.

Step 5 Making NADPH Excited electrons combine with H^+ ions and an electron acceptor called $NADP^+$ to form NADPH. NADPH is an electron carrier that provides the high-energy electrons needed to store energy in organic molecules. Both NADPH and the ATP made during the first stage of photosynthesis will be used to provide the energy to carry out the final stage of photosynthesis.

Reading Check *Summarize how ATP and NADPH are formed during photosynthesis.*

READING TOOLBOX

Describing Space Use spatial language to describe production of ATP and NADPH during photosynthesis.

Differentiated Instruction

Basic Learners/Special Education Students

NADPH Have students make a model of NADPH from clay or some other moldable material. Make the H in the model so that it can be taken on and off and demonstrate how the molecule accepts and donates electrons as it changes between the two. Visually-impaired students can use the best models to follow the process of NADPH production. LS **Visual/Kinesthetic**

QuickLab

Teacher's Notes Discuss strategies for measuring the photosynthetic rate. Suppose the rate was inferred by measuring the amount of generated oxygen. Tell students that at very low light levels, the oxygen level does not increase, because any generated gas is absorbed by the cell for respiration. At higher levels, the generated oxygen is much greater than the needs of the cells and therefore its accumulation can be used to infer rate.

Answers to Analysis

1. At first, the rate steadily increases. Then, the rate slows. It soon levels off, remaining at peak value.
2. It won't. At a certain point, increasing intensity has no effect on the rate.
3. The rate steadily increases, peaks, then steadily decreases.
4. Plant growth might increase initially, but increased temperatures might also kill unadapted plants.

READING TOOLBOX

Describing Space Steps in ATP production are as follows: Water splitting occurs *within the thylakoid.* Hydrogen ions are pumped *into the thylakoid* by a protein that acts as a membrane pump. ATP synthase, *in a channel protein,* catalyzes the reaction to make ATP from ADP.
Steps in NADPH production are as follows: Light reenergizes electrons in *chlorophyll.* Excited electrons, hydrogen ions, and $NADP^+$ react in the *thylakoid.*

Teach, *continued*

Teaching Key Ideas

The Calvin Cycle Have students count the total number of carbon atoms present at each step in the summary of the Calvin cycle in **Figure 8.** Ask students the following questions: "How are ATP and NADPH important to the Calvin cycle?" (They supply energy used to form new compounds.) "How many carbon dioxide molecules are needed?" (3) "How many 3-carbon sugars are made?" (6) "How many of these sugars are actually used to make organic compounds that the plant uses for energy?" (1) Emphasize that most of the 3-carbon sugars are "recycled" and used to make the starting 5-carbon compound that begins the cycle again. **LS Visual**

Why It Matters

Increasing Levels of Carbon Dioxide In general, higher carbon dioxide levels mean that more biomass, or plant tissue, is made during photosynthesis. This increase in biomass may help to counter the effects of rising carbon dioxide levels caused by burning fossil fuels. Other effects appear to be a reduction of nutrients in plant tissues, which may impact the heterotrophs that feed on plants.

Calvin cycle a biochemical pathway of photosynthesis in which carbon dioxide is converted into glucose using ATP and NADPH

Academic Vocabulary

method a way of doing something

Producing Sugar

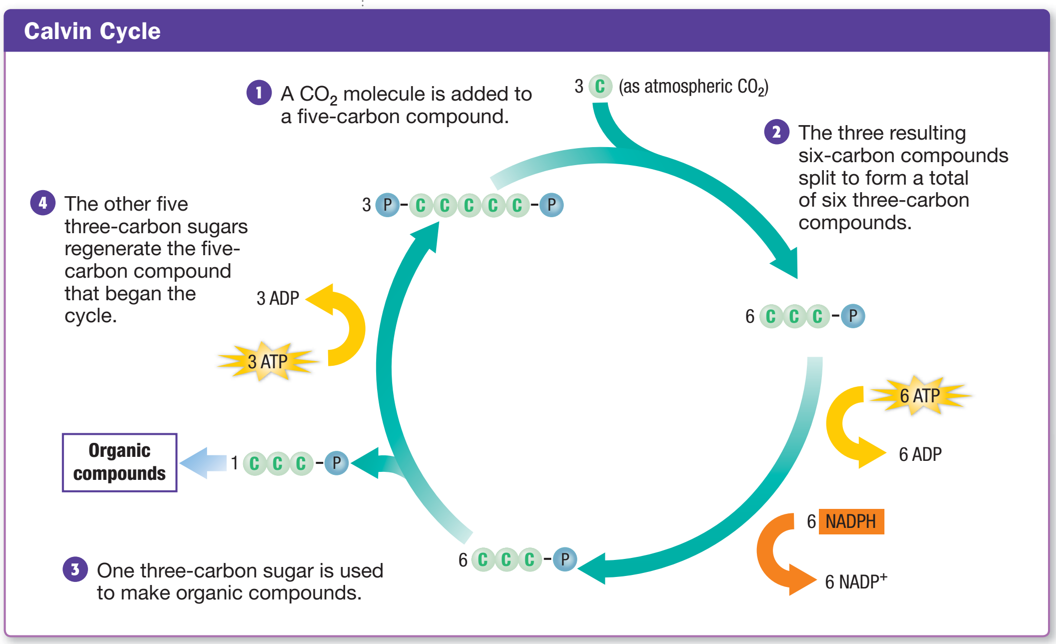
The first two stages of photosynthesis depend directly on light because light energy is used to make ATP and NADPH. **In the final stage of photosynthesis, ATP and NADPH are used to produce energy-storing sugar molecules from the carbon in carbon dioxide.** The use of carbon dioxide to make organic compounds is called *carbon dioxide fixation,* or *carbon fixation.* The reactions that fix carbon dioxide are light-independent reactions, sometimes called *dark reactions.* Among photosynthetic organisms, there are several ways in which carbon dioxide is fixed. The most common method of carbon dioxide fixation is the **Calvin cycle,** which is described in the following steps:

Step 1 Carbon Fixation In carbon dioxide fixation, an enzyme adds a molecule of carbon dioxide, CO_2, to a five-carbon compound. This process occurs three times to yield three six-carbon molecules.

Step 2 Transferring Energy Each six-carbon compound splits into two three-carbon compounds. Phosphate groups from ATP and electrons from NADPH are added to the three-carbon compounds to form higher energy three-carbon sugars.

Step 3 Making Sugar One of the resulting three-carbon sugars leaves the cycle and is used to make organic compounds—including glucose, sucrose, and starch—in which energy is stored for later use by the organism.

Figure 8 The Calvin cycle is the most common method of carbon dioxide fixation. **What is formed when the three six-carbon molecules split during step 2 of the Calvin cycle?**



Differentiated Instruction

Basic Learners

Role Playing Form six groups of students for a peer learning activity. Assign one of the following factors to each group: water, chlorophyll, light, carbon dioxide, NADPH, and ATP. Have each group decide on the role their factor plays in photosynthesis. After a designated time, select a person in each group to describe the role to the rest of the class. Encourage students to be creative. **LS Interpersonal**

Alternative Assessment

Calvin Cycle Have students describe the events of the Calvin Cycle from the perspective of one of the carbon atoms in a CO_2 molecule. Students should include the main steps of the process and what happens to "them" as a carbon atom in each step.

Figure 9 Some plants, such as a cactus (left), grow in extremely sunny, dry environments. Others, such as the bromeliad (right), are able to grow in shady areas.

Step ④ Recycling The remaining five three-carbon sugars are rearranged. Using energy from ATP, enzymes reform three molecules of the initial five-carbon compound. This process completes the cycle. The reformed compounds are used to begin the cycle again.

Factors that Affect Photosynthesis

❯ Light intensity, carbon dioxide concentration, and temperature are three environmental factors that affect photosynthesis. The most obvious of these factors is light. **Figure 9** shows plants that are adapted to different levels of light. In general, the rate of photosynthesis increases as light intensity increases until all of the pigments in a chloroplast are being used. At this saturation point, the rate of photosynthesis levels off because the pigments cannot absorb more light.

The concentration of carbon dioxide affects the rate of photosynthesis in a way similar to light. Once a certain concentration of carbon dioxide is present, photosynthesis cannot proceed any faster.

Photosynthesis is most efficient in a certain range of temperatures. Like all metabolic processes, photosynthesis involves many enzyme-assisted chemical reactions. Unfavorable temperatures may inactivate certain enzymes so that reactions cannot take place.

❯ Reading Check *How does temperature affect photosynthesis?*

Section 2 Review

❯ KEY IDEAS

1. **Summarize** how autotrophs capture the energy in sunlight.
2. **Compare** the roles of water molecules and H^+ ions in electron transport chains.
3. **Describe** the role of the Calvin cycle in photosynthesis.
4. **Name** the three main environmental factors that affect the rate of photosynthesis in plants.

CRITICAL THINKING

5. **Organizing Information** Make a table in which you identify the role of each of the following in photosynthesis: light, water, pigments, ATP, NADPH, and carbon dioxide.

METHODS OF SCIENCE

6. **Inferring Relationships** How do you think photosynthesis will be affected if the sun's rays are blocked by clouds or by smoke from a large fire? How might the levels of atmospheric carbon dioxide and oxygen be affected? What experiments could scientists conduct in the laboratory to test your predictions?

Answers to Caption Questions

Figure 8: three-carbon molecules

Teaching Key Ideas

Identifying Variables Have students list three factors that would increase the rate of photosynthesis. Have them identify what stage of photosynthesis each factor would affect. (Sample answers might include increasing light intensity, which would affect Stage 1; providing more water, which would affect Stage 2; and increasing the carbon dioxide concentration, which would affect Stage 3.)

❯ Close

Formative Assessment

Which of the following provides hydrogen ions for photosynthesis?

A. sunlight (Incorrect. Sunlight excites the electrons in the electron transport chain.)
B. ATP (Incorrect. ATP stores chemical energy.)
C. carbon dioxide (Incorrect. Carbon dioxide provides carbon for the sugar products.)
D. water (Correct! Water is split and provides hydrogen ions for the reaction.)

Answers to Section Review

1. Certain pigments within cells absorb specific wavelengths of light energy. Light energy excites electrons.
2. Water molecules are split to provide new electrons for the electron transport chain and hydrogen ions. The excited electrons provide energy used to pump even more hydrogen ions into the thylakoid. The hydrogen ions then diffuse out of the thylakoid in a process that makes ATP.
3. Carbon dioxide is used in the Calvin cycle to produce a 3-carbon sugar that will be used to produce glucose and other organic compounds. Most of the 3-carbon sugars are recycled.
4. light, carbon dioxide concentration, and temperature
5. Answers will vary, but may be similar to the table shown.

Light	Excites electrons
Water	Provides hydrogen ions and replacement electrons
Pigments	Absorb light
ATP and NADPH	Store chemical energy
Carbon dioxide	Used to produce organic compounds

6. The photosynthetic rate should decrease due to lower light intensity, which should result in a rise in atmospheric CO_2 and a decrease in oxygen. This will affect all living things that require O_2 for respiration. Scientists might study the effect of reduced light intensity by creating a mini ecosystem that includes autotrophs and heterotrophs in a controlled environment with limited sun exposure.

Section 3

Focus

This section describes how organic compounds are processed to form ATP, the energy currency of all cells. Students will learn the basic events of glycolysis and cellular respiration, as well as alternate energy pathways that take place in the absence of oxygen.

Bellringer

Use the Bellringer transparency to prepare students for this section.

Teach

Teaching Key Ideas

Fermentation Ask students what they know about fermentation. Students may speak of rotting, foul smells, or alcohol production. Explain that fermentation is a way that cells are able to make ATP in the absence of oxygen. Fermentation can cause foul odors. It also helps produce cheese, yogurt, bread, and wine. LS Verbal

Answers to Caption Questions

Figure 10: photosynthesis
Figure 11: glucose

Section 3 Cellular Respiration

Key Ideas	Key Terms	Why It Matters
How does glycolysis produce ATP? How is ATP produced in aerobic respiration? Why is fermentation important?	glycolysis anaerobic aerobic Krebs cycle fermentation	Cellular respiration is the process used by humans and most other organisms to release the energy stored in the food they consume.

Where do the students shown in **Figure 10** get energy? Most of the foods we eat contain energy. Much of the energy in a hamburger, for example, is stored in proteins, carbohydrates, and fats. But before you can use that energy, it must be released and transferred to ATP. Like cells of most organisms, your cells transfer the energy in organic compounds, especially the glucose made during photosynthesis, to ATP through cellular respiration, which begins with glycolysis.

Glycolysis

The primary fuel for cellular respiration is glucose, which is formed when carbohydrates, such as starch and sucrose, are broken down. If too few carbohydrates are available to meet an organism's energy needs, other molecules, such as fats, can be broken down to make ATP. In fact, one gram of fat releases more energy than two grams of carbohydrates do. Proteins and nucleic acids can also be used to make ATP, but they are usually used for building important cell parts.

Figure 10 These students get their energy by eating carbohydrates, fats, proteins, and other organic molecules. **What is the origin of the energy-containing organic molecules in these students' food?**

Key Resources

Transparencies
B53 Cellular Respiration
B37 Glycolysis
B39 Krebs Cycle
B54 Electron Transport Chain of Aerobic Respiration

Visual Concepts
Cellular Respiration
Glycolysis
NAD^+ and NADH
Krebs Cycle
FAD and $FADH_2$
Fermentation

Differentiated Instruction

Basic Learners

Relating Processes Ask students to answer the following questions in their notebooks: How are the products of photosynthesis and cellular respiration related? (The products of photosynthesis are the starting materials for cellular respiration.) What kinds of organisms undergo cellular respiration? (All organisms, including photosynthetic organisms, undergo cellular respiration.) LS Logical

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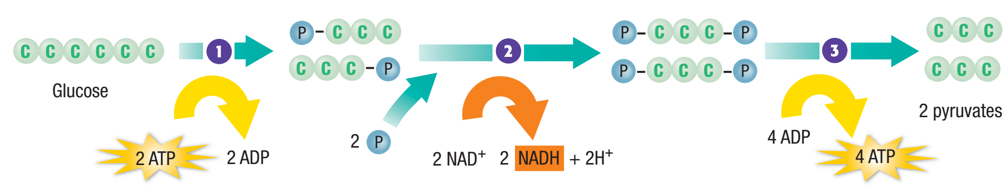
Glycolysis



1 Two ATP molecules are used to break glucose into two smaller units. A phosphate group is added to the 6-carbon compound.

2 Each 3-carbon compound reacts with a phosphate group. Hydrogen atoms are transferred to NAD^+, producing NADH.

3 Each 3-carbon sugar is converted to a 3-carbon molecule of pyruvate. Four ATP molecules are produced.

Figure 11 Glycolysis uses two ATP molecules but produces four ATP molecules. The process results in a net gain of ATP. **› What is the starting material in glycolysis?**

Steps of Glycolysis In the first stage of cellular respiration, glucose is broken down in the cytoplasm by glycolysis. In **glycolysis,** enzymes break down one six-carbon molecule of glucose into two three-carbon pyruvate molecules, as **Figure 11** shows. Most of the energy that was stored in the glucose molecule is stored in the pyruvate.

Step 1 Breaking Down Glucose In the first stage of glycolysis, two ATP molecules are used to break glucose into two smaller units. This stage has four steps with four different enzymes. A phosphate group from ATP is added to the six-carbon compound. This makes the molecule reactive so that an enzyme can break it into two three-carbon sugars, each with a phosphate group. ATP is produced in the next two stages.

Step 2 NADH Production In the second stage, each three-carbon compound reacts with another phosphate group (not from ATP). As the two three-carbon sugars react further, hydrogen atoms, including their electrons, are transferred to two molecules of NAD^+, which produces two molecules of the electron carrier NADH. NADH is used later in other cell processes, where it is recycled to NAD^+.

Step 3 Pyruvate Production In a series of four reactions, each three-carbon sugar is converted into a three-carbon molecule of pyruvate. This process produces four ATP molecules. **› Thus, the breaking of a sugar molecule by glycolysis results in a net gain of two ATP molecules.**

Glycolysis is the only source of energy for some prokaryotes. This process is **anaerobic,** so it takes place without oxygen. Other organisms use oxygen to release even more energy from a glucose molecule. Metabolic processes that require oxygen are **aerobic.** In aerobic respiration, the pyruvate product of glycolysis undergoes another series of reactions to produce more ATP molecules.

› Reading Check *What are the three products of glycolysis?*

glycolysis (glie KAHL i sis) the anaerobic breakdown of glucose to pyruvate, which makes a small amount of energy available to cells in the form of ATP

anaerobic (AN uhr OH bik) describes a process that does not require oxygen

aerobic (er OH bik) describes a process that requires oxygen

SCILINKS.
www.scilinks.org
Topic: Cellular Respiration
Code: HX80244

go.hrw.com
interact online

Students can interact with the stages of "Glycolysis" by going to go.hrw.com and typing in the keyword HX9PHRF11.

Teaching Key Ideas

Metabolic Pathways Review the term *metabolism* with students. (Metabolism describes the sum of all chemical reactions within an organism.) Tell students that glycolysis is an example of a metabolic pathway. In glycolysis, the energy stored in glucose is gradually released in a series of enzyme-assisted chemical reactions. **LS Verbal**

Why It Matters

Life Without Oxygen Early life probably used glycolysis to make ATP long before oxygen was present in Earth's atmosphere. According to fossil records, prokaryotes were present on Earth 3.5 billion years ago, but oxygen was not abundant in the atmosphere until around 2.5 billion years ago. Because glycolysis is an anaerobic metabolic pathway that occurs in all cells, glycolysis most likely occurred in early cells.

Differentiated Instruction

Basic Learners

Glycolysis Have students examine **Figure 11,** and ask them to identify the starting material in glycolysis. (glucose) Work with students to summarize the events that take place in each step. Explain that as glucose is broken down during glycolysis, some of the energy contained in glucose is transferred to the products of glycolysis. Ask students to identify these products. (pyruvate, ATP, and NADH) Explain that pyruvate is the ion of the organic molecule pyruvic acid. **LS Visual**

❯ Teach, *continued*

Teaching Key Ideas

Coenzymes A coenzyme is an organic chemical that is necessary for the action of many enzymes. Ask students why it is important for glucose to be partially broken down to pyruvate. (The formation of pyruvate releases some energy.) Tell students that when pyruvate enters a mitochondrion and is broken down to a 2-carbon acetyl group, coenzyme A attaches to the acetyl group, forming acetyl-CoA. Coenzyme A enables the acetyl group to enter the Krebs cycle.

Teaching Key Ideas

The Krebs Cycle Guide students through the steps of **Figure 12.** Have students count the number of carbon atoms present at each step during the Krebs cycle. Ask them where the Krebs cycle occurs. (in mitochondria) Remind students that for every molecule of glucose that is broken down, two pyruvate ions are produced. Thus the Krebs cycle occurs for each pyruvate. Also tell them that a specific enzyme is involved in each step. Emphasize the role of the Krebs cycle as a precursor of the electron transport chain. **LS Visual**

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Students can interact with the "Krebs Cycle" by going to go.hrw.com and typing in the keyword HX8PHRF12.

Krebs Cycle

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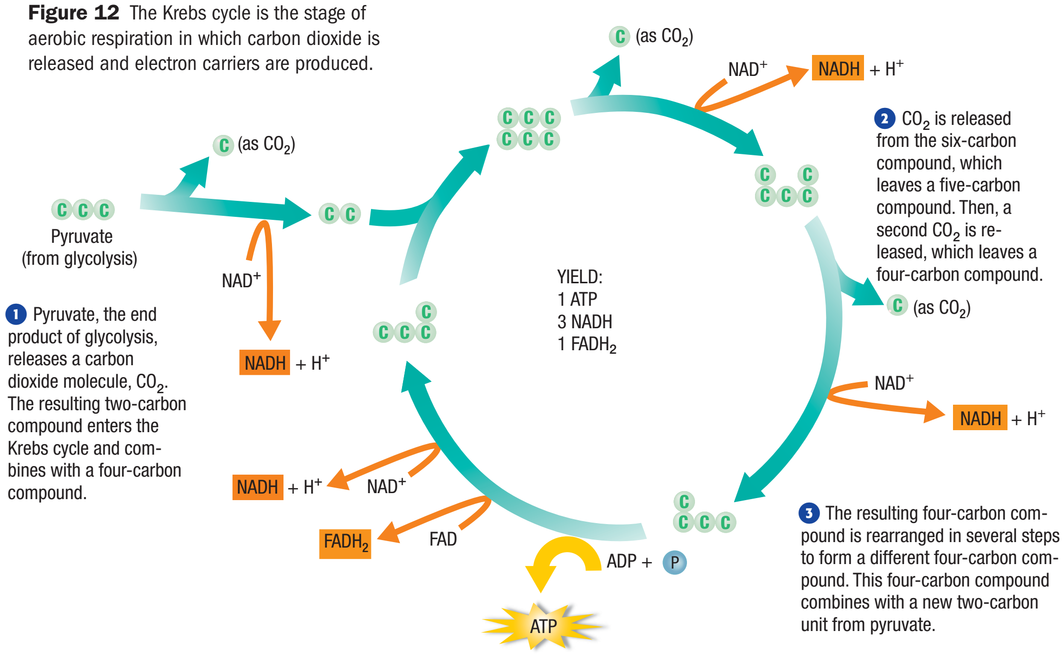
Keyword: HX8PHRF12

Figure 12 The Krebs cycle is the stage of aerobic respiration in which carbon dioxide is released and electron carriers are produced.



Krebs cycle a series of biochemical reactions that convert pyruvate into carbon dioxide and water

Aerobic Respiration

Organisms such as humans can use oxygen to produce ATP efficiently through aerobic respiration. Pyruvate is broken down in the **Krebs cycle,** a series of reactions that produce electron carriers. The electron carriers enter an electron transport chain, which powers ATP synthase. Up to 34 ATP molecules can be produced from one glucose molecule in aerobic respiration.

Krebs Cycle The first stage of aerobic respiration, the Krebs cycle, is named for Hans Krebs, a German biochemist. He was awarded the Nobel Prize in 1953 for discovering it. As **Figure 12** shows, the Krebs cycle begins with pyruvate, which is produced during glycolysis. Pyruvate releases a carbon dioxide molecule to form a two-carbon compound. An enzyme attaches this two-carbon compound to a four-carbon compound and forms a six-carbon compound.

The six-carbon compound releases one carbon dioxide molecule and then another. Energy is released each time, which forms an electron carrier, NADH. The remaining four-carbon compound is converted to the four-carbon compound that began the cycle. This conversion takes place in a series of steps that produce ATP, then $FADH_2$, and another NADH. The four-carbon compound combines with a new two-carbon unit from pyruvate to continue the cycle.

Products of the Krebs Cycle Each time the carbon-carbon bonds are rearranged or broken, energy is released. **The total yield of energy-storing products from one time through the Krebs cycle is one ATP, three NADH, and one $FADH_2$. Electron carriers transfer energy through the electron transport chain, which ultimately powers ATP synthase.**

Electron Transport Chain The second stage of aerobic respiration takes place in the inner membranes of mitochondria. Recall that electrons pass through a series of molecules called an *electron transport chain,* as **Figure 13** shows. ① The electrons that are carried by NADH and $FADH_2$ pass through this chain. Energy is transferred into each molecule through which the electrons pass. Some of the molecules are hydrogen ion pumps. ② Energy from the electrons is used to actively transport hydrogen ions, H^+, out of the inner mitochondrial compartment. As H^+ ions accumulate in the outer compartment, a concentration gradient across the inner membrane is created.

ATP Production The enzyme ATP synthase is also present on the inner membranes of mitochondria. ③ Hydrogen ions diffuse through a channel in this enzyme. This movement provides energy, which is used to produce several ATP molecules from ADP.

The Role of Oxygen At the end of the electron transport chain, the electrons have given up most of their energy. ④ An oxygen atom combines with these electrons and two H^+ ions to form two water molecules, H_2O. If oxygen is not present, the electron transport chain stops. The electron carriers cannot be recycled, so the Krebs cycle also stops. Without oxygen, a cell can produce ATP only by glycolysis.

Reading Check ***Why is glycolysis important to the Krebs cycle?***

READING TOOLBOX

Pattern Puzzles Make a pattern puzzle to help you remember the steps in aerobic respiration.

Figure 13 Along the inner mitochondrial membrane, an electron transport chain produces a hydrogen ion gradient. The diffusion of hydrogen ions provides energy for the production of ATP by ATP synthase.

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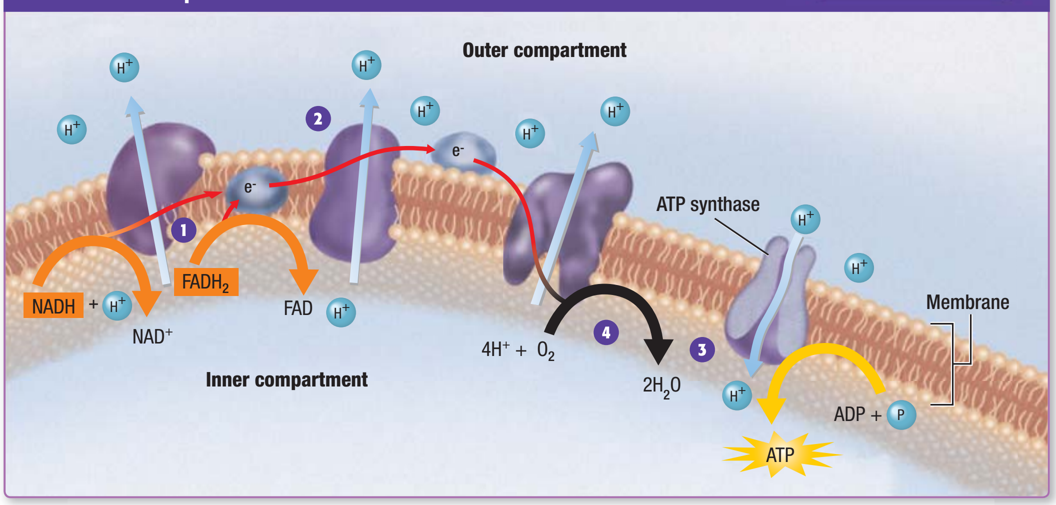
Electron Transport Chain



READING TOOLBOX

Pattern Puzzles Puzzle parts should include the following: electrons carried by NADH and $FADH_2$; hydrogen ions pumped from the inner to outer mitochondrial compartment; hydrogen ions diffuse through ATP synthase channel; oxygen, electrons, and hydrogen ions react to form water; Krebs cycle begins with pyruvate and produces 1 ATP, 3NADH, and $1FADH_2$

Teaching Key Ideas

Electron Transport Ask students how the electron transport chains of photosynthesis and cellular respiration are similar. (In both processes, electrons are passed along an electron transport chain and are picked up by an electron acceptor. The energy of these electrons is used to produce a hydrogen ion concentration gradient, which provides the energy needed to make ATP.)

Math Skills

ATP Molecules The human body uses about 1 million molecules of ATP per cell per second. There are more than 100 trillion cells in the human body. That's about 1×10^{20}, or 100,000,000,000,000,000,000 ATP molecules used in your body each second.

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Students can interact with the "Electron Transport Chain" by going to go.hrw.com and typing in the keyword HX8PHRF13.

Differentiated Instruction

Basic Learners/Struggling Readers

Electron Transport Chain Have students follow the path of electrons, shown by the red arrows, through the electron transport chain in **Figure 13.** Point out that the energy of these electrons is used to pump hydrogen ions out of the inner compartment. Ask students to identify this type of transport. (active transport) These ions then diffuse back into the inner compartment through the specialized carrier protein, ATP synthase, providing enough energy to make ATP. Ask students to identify this type of transport. (passive transport) Ask students why the folds of the mitochondria are important. (They increase the surface area of the membranes, which allows more ATP to be made.) Ask students to identify the role of oxygen in the electron transport chain. (Oxygen is the final electron acceptor, and water is produced when the spent electrons, hydrogen ions, and oxygen combine.) **LS Visual**

Teach, *continued*

Teaching Key Ideas

Effects of Exercise Invite one of the physical education teachers or coaches from your school to discuss the physiological effects of exercise on the body. Be certain that the speaker discusses oxygen debt, muscle fatigue, the role of myoglobin in muscles, and the role of lactate in muscle soreness. **LS Intrapersonal**

Why It Matters

Cyanide Students may be familiar with the poison cyanide. Tell students that cyanide is a fast-acting poison that blocks the action of the electron transport chain. It exists as hydrogen cyanide gas or cyanide salts used in gold and other metal extractions, electroplating, and metal cleaning. Cyanide enters the body by absorption through the lungs, skin, or gastrointestinal tract. It is highly toxic, and symptoms appear soon after exposure. Ingesting as little as 3 grams of cyanide can soon be fatal.

Answers to Caption Questions

Figure 14: Possible answer: Lactic acid fermentation produces lactate, while alcoholic fermentation produces carbon dioxide and ethanol.
Figure 15: The electron transport chain that occurs during aerobic respiration

ACADEMIC VOCABULARY

transfer to carry or remove something from one thing to another

fermentation the breakdown of carbohydrates by enzymes, bacteria, yeasts, or mold in the absence of oxygen

Fermentation

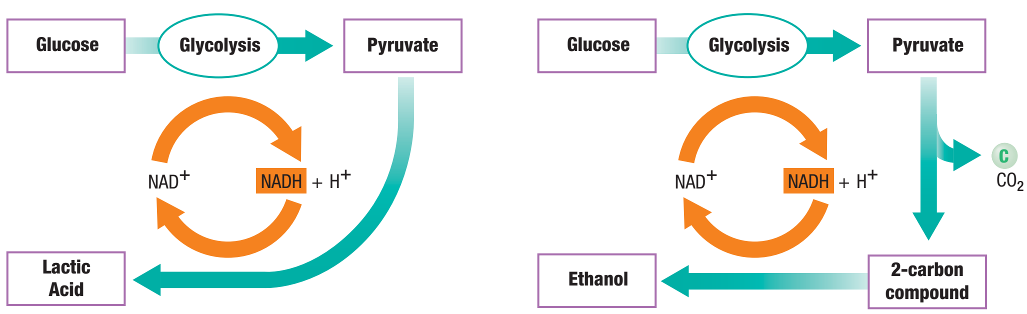
Many prokaryotes live entirely on the energy released in glycolysis. Recall that glycolysis produces two ATP molecules and one molecule of the electron carrier NADH. The NADH must be able to transfer its electrons to an acceptor so that NAD^+ is continuously available. Under anaerobic conditions, the electron transport chain, if present, does not work. Organisms must have another way to recycle NAD^+. So, electrons carried by NADH are transferred to pyruvate, which is produced during glycolysis. This process in which carbohydrates are broken down in the absence of oxygen, called **fermentation,** recycles the NAD^+ that is needed to continue making ATP through glycolysis. **Fermentation enables glycolysis to continue supplying a cell with ATP in anaerobic conditions.** Two types of fermentation are lactic acid fermentation and alcoholic fermentation.

Lactic Acid Fermentation Recall that the end products of glycolysis are three-carbon pyruvate molecules. In some organisms, pyruvate accepts electrons and hydrogen from NADH. Pyruvate is converted to lactic acid in a process called *lactic acid fermentation,* as **Figure 14** shows. Lactic acid fermentation also occurs in the muscles of animals, including humans. During vigorous exercise, muscle cells must operate without enough oxygen. So, glycolysis becomes the only source of ATP as long as the glucose supply lasts. For glycolysis to continue, NAD^+ is recycled by lactic acid fermentation.

Alcoholic Fermentation In other organisms, an enzyme removes carbon dioxide from the three-carbon pyruvate to form a two-carbon molecule. Then, a second enzyme adds electrons and hydrogen from NADH to the molecule to form ethanol (ethyl alcohol) in a process called *alcoholic fermentation.* In this process, NAD^+ is recycled and glycolysis can continue to produce ATP.

Reading Check *Explain how fermentation recycles* NAD^+.

Figure 14 When oxygen is not present, cells recycle NAD^+ through fermentation. **Compare lactic acid fermentation with alcoholic fermentation.**



Lactic acid fermentation
In lactic acid fermentation, pyruvate is converted to lactic acid.

Alcoholic fermentation
In alcoholic fermentation, pyruvate is broken down to ethanol, releasing carbon dioxide.

Differentiated Instruction

English Learners

Fermentation Have students work in groups of four. Each group should brainstorm a list of foods and legal beverages that make use of fermentation. Students may wish to use the Web to expand their lists. For presentation, students should prepare a poster, using drawings or pictures of fermentation products cut from magazines. (Answers will vary, but could include various breads, pizza, various cheeses, soy sauce, doughnuts, etc.) **LS Interpersonal**

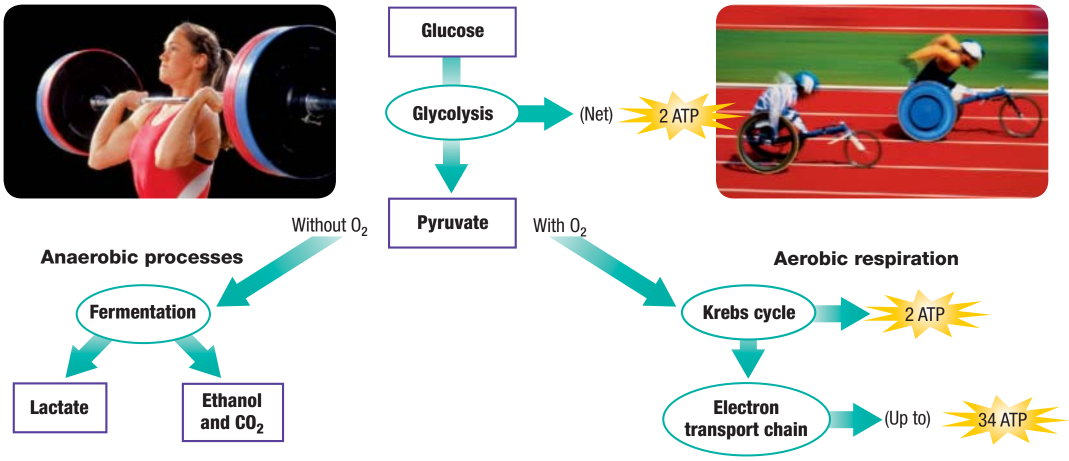


Figure 15 Most ATP is produced during aerobic respiration. **❯ Which cellular respiration process produces ATP molecules most efficiently?**

Efficiency of Cellular Respiration The total amount of ATP that a cell harvests from each glucose molecule depends on the presence or absence of oxygen. **Figure 15** compares the amount of ATP produced in both cases.

In the first stage of cellular respiration, glucose is broken down to pyruvate during glycolysis. Glycolysis is an anaerobic process, and it results in a net gain of two ATP molecules.

In the second stage of cellular respiration, pyruvate either passes through the Krebs cycle or undergoes fermentation. When oxygen is not present, fermentation occurs. The NAD^+ that is recycled during fermentation allows glycolysis to continue producing ATP.

Cells release energy most efficiently when oxygen is present because they make most of their ATP during aerobic respiration. For each molecule of glucose that is broken down, as many as two ATP molecules are made during the Krebs cycle. The Krebs cycle feeds NADH and $FADH_2$ to the electron transport chain. The electron transport chain can produce up to 34 ATP molecules.

Section 3 Review

❯ KEY IDEAS

1. **List** the products of glycolysis, and explain the role of each of these products in both aerobic respiration and anaerobic respiration.
2. **Summarize** the roles of the Krebs cycle and the electron transport chain during aerobic respiration.
3. **Describe** the role of fermentation in the second stage of cellular respiration.

CRITICAL THINKING

4. **Inferring Conclusions** Excess glucose in your blood is stored in your liver as glycogen. How might your body sense when to convert glucose to glycogen and glycogen back to glucose again?

ALTERNATIVE ASSESSMENT

5. **Analyzing Methods** Research ways that fermentation is used in food preparation. Find out what kinds of microorganisms are used in cultured dairy products, such as yogurt, sour cream, and some cheeses. Research the role of alcoholic fermentation by yeast in bread making. Prepare an oral report to summarize your findings.

Answers to Section Review

1. Pyruvate: if oxygen is present, pyruvate will enter the Krebs cycle; if oxygen is absent, pyruvate will undergo fermentation. NADH: if oxygen is present, NADH will enter the electron transport chain. ATP: temporarily stores energy for cellular processes.
2. The Krebs cycle produces electron carriers that donate electrons to the electron transport chain. The electron transport chain produces most of the ATP that is produced in cellular respiration.
3. Fermentation recycles NAD^+, which is needed to continue ATP production in the absence of oxygen.
4. Sensors in the body monitor the level of glucose in the blood. When the blood glucose level is high, the storage of glycogen is stimulated. When the blood glucose levels is low, glucose is released back into the blood.
5. Answers will vary. Bacteria are used to make yogurt, sour cream, and some cheeses. Other cheeses are made with the help of fungi. During bread making, alcoholic fermentation by yeast produces alcohol, which evaporates, and carbon dioxide, which makes the bread rise.

Teaching Key Ideas

Fermentation Demonstration
Thoroughly mix half a packet of yeast with about 400 mL of warm water. Pour the mixture into an Erlenmyer flask or beaker. Add a few drops of bromothymol blue indicator and set the flask aside. Ask students what the bubbles indicate. (Carbon dioxide is being released by the yeast.) By the end of the class period, the blue yeast mixture should turn yellow. Ask students why this happens. (The indicator turns yellow in the presence of an acid; when carbon dioxide is produced by the yeast, carbonic acid is formed in the water.) **LS Visual**

❯ Close

Formative Assessment

Which of the following is an aerobic process?

A. the Krebs cycle (Correct! The Krebs cycle is an aerobic process.)
B. glycolysis (Incorrect. Glycolysis is an anaerobic process.)
C. alcoholic fermentation (Incorrect. Alcoholic fermentation is an anaerobic process.)
D. lactic acid fermentation (Incorrect. Lactic acid fermentation is an anaerobic process.)

Why It Matters

Teacher's Notes The development of a sustainable, highly productive, and nonpolluting agriculture system is a major achievement of Biosphere 2. During the first year of the initial project, the eight-member crew produced 7 tons of foodstuffs for humans and 15 tons of fodder for the domestic animals. Their diet consisted mainly of fruits, grains, vegetables, peanuts, and small quantities of goat milk and yogurt. Because of the low-calorie, low-fat, nutrient-dense diet, the biospherians lost on average 16% of their body weight and had a 35% reduction in blood cholesterol. The chemical-free agricultural system recycled all human and domestic animal waste, marking the first time complete waste recycling was accomplished in a biological life support system. All water was recycled using a sophisticated system with over 20 subsystems. This maintained the wide diversity of water quality required—from the salt water of ocean and marsh systems, to the rainwater needed by rain forest, savanna, desert, and farm—to the high purity levels required for drinking. The interior portion of Biosphere 2 was opened to the public in 2002. Visitors are allowed to tour the world-renowned structure following a series of trails that lead through the ecosystems.

Answer to Research

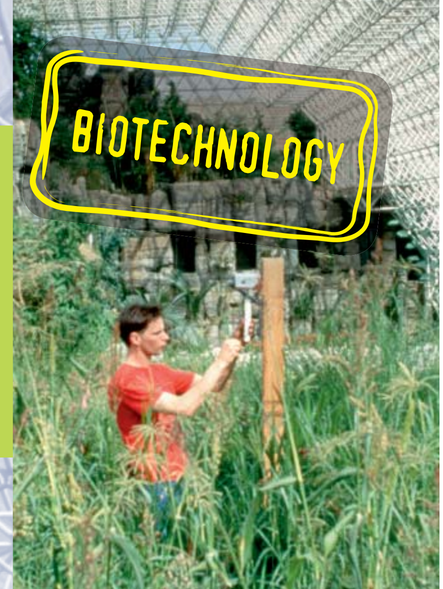
Several of the creators of the Biosphere 2 project are now developing the Mars on Earth Project. The Mars on Earth project is a long-term program to design, construct, and operate an Earth-based prototype life support system that simulates a base for a manned mission to Mars.

Why It Matters

Life in a Biosphere

BIOTECHNOLOGY

The Biosphere 2 research facility has seven ecosystems that mirror those on Earth, including a desert, a savannah, a saltwater ocean that contains a million gallons of water, an Amazonian rain forest, a mangrove marsh, an area of intensive agriculture, and a habitat for humans. The giant, self-contained system of Biosphere 2 is a miniature version of the flows and balances that occur on Earth. But in Biosphere 2, they are occurring at a much faster pace.

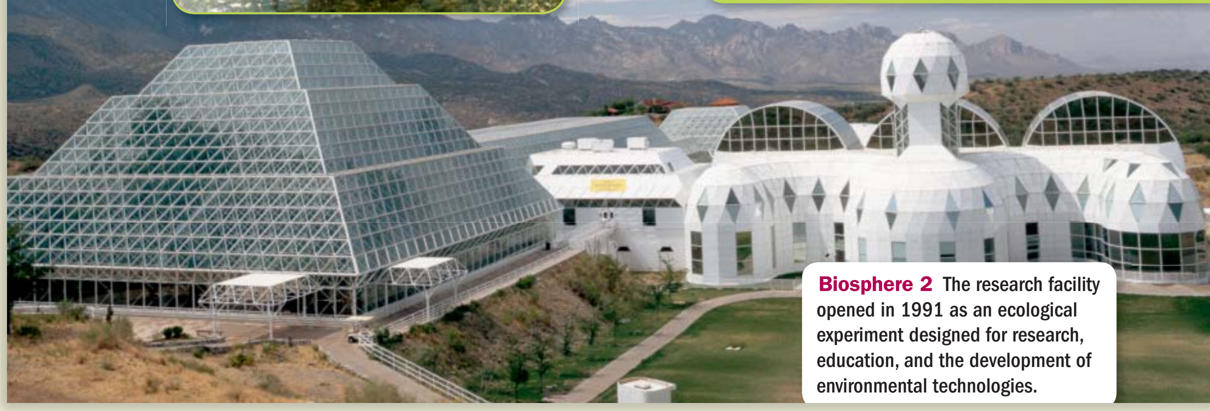


A World Under Glass

Located on 3.15 acres in southern Arizona, this miniature, airtight world is sealed on the bottom by a stainless steel liner and on the top by a steel and glass structure. The seven ecosystems were built from scratch with soils, water, and plant and animal life from around the world. Biosphere 2 has more than 1,000 sensors that monitor the vital statistics of this living laboratory by measuring temperature, humidity, oxygen, carbon dioxide, and other qualities of the air and soil.

Biospherians Eight researchers, known as *biospherians,* lived entirely within the facility. They controlled the technical systems and gathered results for more than 60 research projects, including studies of carbon dioxide and oxygen cycles, soil composition, coral reef health, agricultural pest management, and waste and water recycling.

Quick Project Biosphere 2 research is being used to help develop environmental technologies for use in space. Find out details about the Mars on Earth Project and its connection to Biosphere 2.



Biosphere 2 The research facility opened in 1991 as an ecological experiment designed for research, education, and the development of environmental technologies.

Skills Practice

Chapter 9 Lab

45 min

Objectives

- Demonstrate how carbon dioxide affects bromothymol blue when added to the indicator solution.
- Describe the effect of temperature on carbon dioxide production by yeast.

Materials

- safety goggles
- disposable gloves
- lab apron
- plastic cups, clear (4)
- room temperature water
- bromothymol blue
- drinking straw, plastic
- warm water
- ice water
- baker's yeast
- ¼ teaspoon
- hand lens
- sugar

Safety

Cellular Respiration

In cellular respiration, sugar is broken down and energy is released. This energy is harnessed and used to produce ATP. In addition to releasing energy, respiration generates reaction byproducts such as carbon dioxide gas. Carbon dioxide readily dissolves in water to produce a mild acid. This change to an acid can be confirmed through the use of an acid-base indicator, such as bromothymol blue. In this activity, you will use bromothymol blue to confirm respiration, and you will explore how temperature may affect this metabolic process.

Procedure

1. Put on safety goggles, gloves, and a lab apron. Fill a clean plastic cup halfway with room temperature water. Add several drops of bromothymol blue to the water. Swirl to mix the solution. **CAUTION: Bromothymol blue is a skin and eye irritant.**
2. Insert a clean straw into the solution. Gently blow a steady stream of air through the straw. Note any changes in the solution's appearance. **CAUTION: Be careful not to accidentally drink the solution while blowing into the straw.**
3. Label three plastic cups, "A," "B" and "C."
4. Fill cup A with ice water, fill cup B with room temperature water, and fill cup C with warm water. Add several drops of bromothymol blue solution to each cup to ensure a uniform appearance.
5. Add ¼ teaspoon of baker's yeast to each cup. Swirl the cups, and observe the appearance of the solutions every 30 s. After 5 min, examine the surface of each solution with a hand lens.
6. Clean up your lab materials according to your teacher's instructions. Wash your hands before leaving the lab.

Analyze and Conclude

1. **Drawing Conclusions** What happened to the indicator as exhaled air bubbled through the solution? What caused this change?
2. SCIENTIFIC METHODS **Evaluating Results** Did the yeast produce a similar color change? Explain your answer.
3. SCIENTIFIC METHODS **Evaluating Results** Did temperature affect the yeast's production of carbon dioxide? Explain your answer.
4. SCIENTIFIC METHODS **Summarizing Results** What did you observe on the surface of the solutions?
5. **Predicting Outcomes** Will adding sugar to the yeast solution affect the respiration rate? Make a guess. Then, design a method for inquiry that would test the effects of various sugar concentrations on yeast metabolism.

Answers to Analysis and Conclusions

1. The indicator changed from blue to yellow. The carbon dioxide in exhaled air reacted in water forming a mild acid. This acid caused a color change in the indicator solution.
2. Yes. As yeast cells respired, they generated carbon dioxide gas. This gas produced a mild acid that caused the indicator to change color.
3. Yes. Yeast in the warmest water produced the quickest change in indicator appearance. Yeast in the ice water produced a very minimal change in the indicator's appearance.
4. The surface of the warm water and room-temperature water had tiny bubbles. These bubbles most likely contained carbon dioxide that was generated by the respiring yeast.
5. Answers will vary. Students may guess that adding sugar to the solution will cause the respiration rate to increase. With approval of the experimental design, offer students the supplies and tools they need to carry out their proposed experiments. Testing sugar concentrations on yeast metabolism can be performed during a lab period.

Lab

Time Required

One 45-minute class period

Ratings

EASY → HARD

Teacher Prep	3
Student Setup	2
Concept Level	3
Cleanup	2

Safety Cautions

Tell students that bromothymol blue is a skin and eye irritant. It can stain skin and clothing. Remind students to be careful not to accidentally drink the solution while blowing into the straw. Make sure students wear safety goggles to protect their eyes from splashes-especially when blowing into the indicator-stained solution. The water used when activating yeast should be warm, not hot.

Tips and Tricks

Make sure that all yeast used in this activity is fresh. Use fast-rising yeast for quicker results. Remind students that the grains contained within the yeast packet are not individual yeast cells. They are freeze-dried clumps of many cells that when activated regain an observable metabolic function.

Bromothymol blue (bromthymol blue), can be obtained locally from pet and tropical fish stores.

Key Resources

- Holt Lab Generator
- Lab Datasheet (Levels A, B, C)
- Holt Science Biology Video Labs
- Virtual Investigations
- HB Dissection Labs

Chapter 9

SUPER SUMMARY

Have students connect the major concepts in this chapter through an interactive Super Summary. Visit **go.hrw.com** and type in the keyword **HX8PHRS** to access the Super Summary for this chapter.

Reteaching Key Ideas

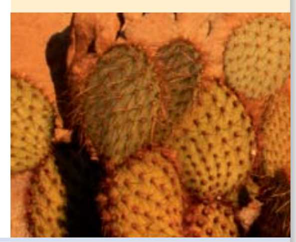
Pick the Right Pathway Assign students to work with a partner. Have each pair evaluate the following scenario. "Suppose you are an organism that can respire aerobically and anaerobically. Which pathway provides the better advantage and why?" (If oxygen is available, aerobic respiration would be the preferred pathway because more ATP is produced.)

Role Play and the Krebs Cycle Have students work in pairs to write a description of the Krebs cycle from the perspective of a sportscaster giving a play-by-play description.

Chapter 9 Summary

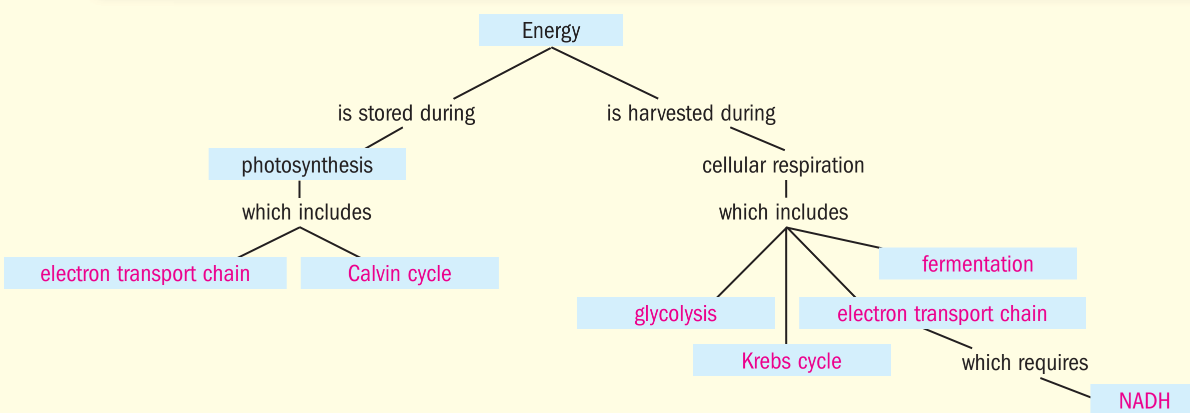
go.hrw.com
SUPER SUMMARY
Keyword: HX8PHRS

Key Ideas	Key Terms
1 Energy in Living Systems • Organisms use and store energy in the chemical bonds of organic compounds. • Metabolism involves either using energy to build organic molecules or breaking down organic molecules in which energy is stored. Organic molecules contain carbon. Therefore, an organism's metabolism is part of Earth's carbon cycle. • In cells, chemical energy is gradually released in a series of chemical reactions that are assisted by enzymes.	**photosynthesis** (197) **cellular respiration** (198) **ATP** (198) **ATP synthase** (201) **electron transport chain** (201)
2 Photosynthesis • In plants, light energy is harvested by pigments located in the thylakoid membrane of chloroplasts. • During photosynthesis, one electron transport chain provides energy used to make ATP, while the other provides energy to make NADPH. • In the final stage of photosynthesis, chemical energy is stored by being used to produce sugar molecules from the carbon in the gas carbon dioxide. • Light intensity, carbon dioxide concentration, and temperature are three environmental factors that affect photosynthesis.	**thylakoid** (202) **pigment** (203) **chlorophyll** (203) **Calvin cycle** (206)
3 Cellular Respiration • The breaking of a sugar molecule by glycolysis results in a net gain of two ATP molecules. • The total yield of energy-storing products from one time through the Krebs cycle is one ATP, three NADH, and one $FADH_2$. Electron carriers transfer energy through the electron transport chain, which ultimately powers ATP synthase. • Fermentation enables glycolysis to continue supplying a cell with ATP in anaerobic conditions.	**glycolysis** (209) **anaerobic** (209) **aerobic** (209) **Krebs cycle** (210) **fermentation** (212)



Answer to Concept Map

The following is one possible answer to Chapter Review question 2.



Chapter 9

Review

READING TOOLBOX

1. **Describing Space** Use spatial language to describe what takes place along the electron transport chain during aerobic respiration.

2. **Concept Map** Make a concept map that shows how photosynthesis and cellular respiration are related. Try to include the following terms in your map: *glycolysis, Krebs cycle, electron transport chain, Calvin cycle, fermentation,* and *NADH.*

Using Key Terms

In your own words, write a definition for each of the following terms.

3. *ATP*
4. *Calvin cycle*
5. *aerobic*
6. *Krebs cycle*
7. *fermentation*

Use each of the following pairs of key terms in the same sentence.

8. *photosynthesis* and *thylakoid*
9. *pigment* and *chlorophyll*
10. *glycolysis* and *anaerobic*

Understanding Key Ideas

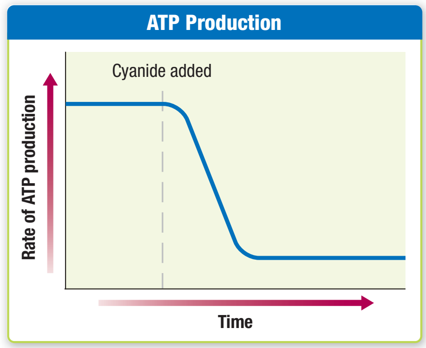
11. Energy flows through living systems from
    a. the sun, to heterotrophs, and then to autotrophs.
    b. the environment, to heterotrophs, and then to autotrophs.
    c. the sun, to autotrophs, and then to heterotrophs.
    d. autotrophs, to the environment, and then to heterotrophs.

12. The products of photosynthesis that begin cellular respiration are
    a. ATP and water.
    b. $NADP^+$ and hydrogen.
    c. carbon dioxide and water.
    d. organic compounds and oxygen.

13. Which of the following occurs in lactic acid fermentation?
    a. Oxygen is consumed.
    b. Lactic acid is converted into pyruvate.
    c. NAD^+ is regenerated for use in glycolysis.
    d. Electrons pass through the electron transport chain.

14. Aerobic respiration involves all of the following *except*
    a. ATP.
    b. glycolysis.
    c. mitochondria.
    d. the Krebs cycle.

Use the graph to answer the following question.



15. **Interpreting Graphics** The graph shows the rate of ATP production by a culture of yeast cells over time. At the time indicated by the dashed line, cyanide was added to the culture. Cyanide blocks the flow of electrons to O_2 from the electron transport chain in mitochondria. Explain why adding cyanide affects ATP production in the way shown by the graph.

Explaining Key Ideas

16. **Differentiate** between autotrophs and heterotrophs.
17. **Identify** the primary source of energy for humans.
18. **Predict** what might happen to photosynthesis if ATP were not produced in the light reactions.
19. **Relate** the rate of photosynthesis to light levels.
20. **Compare** the two stages of cellular respiration.

Assignment Guide

Section	Questions
1	3, 11, 12, 16, 17, 34
2	2, 4, 8, 9, 12, 18, 19, 23, 24, 25, 26, 27, 29, 32
3	1, 2, 5, 6, 7, 10, 12, 13, 14, 15, 20, 21, 22, 27, 28, 30, 31, 33

Review

Reading Toolbox

1. The electron transport chain is a series of molecules located along the *inner* mitochondrial membrane. Some of the molecules are hydrogen ion pumps, which actively transport hydrogen ions *out* of the *inner* mitochondrial compartment. Hydrogen ions accumulate in the *outer* compartment, creating a concentration gradient across the *inner* membrane. Hydrogen ions move *down* the gradient *through* a channel in ATP synthase molecules, which provides energy that is used to produce ATP.
2. See previous page for answer to concept map.

Using Key Terms

3. *Adenosine triphosphate (ATP)* is an organic molecule that acts as the main energy source for cell processes.
4. The *Calvin cycle* is a biochemical pathway of photosynthesis in which carbon dioxide is converted into glucose using ATP.
5. *Aerobic* describes a process that requires oxygen.
6. The *Krebs cycle* is a series of biochemical reactions that convert pyruvic acid into carbon dioxide and water.
7. *Fermentation* is the breakdown of carbohydrates by enzymes, bacteria, yeasts, or mold in the absence of oxygen.
8. The first stages of *photosynthesis* begin when light waves strike stacks of *thylakoids.*
9. *Chlorophyll* is the primary *pigment* involved in photosynthesis.
10. *Glycolysis* is an *anaerobic* process because it does not require the presence of oxygen.

Understanding Key Ideas

11. c 12. d 13. c 14. b

15. Blocking the flow of electrons along the electron transport chain will quickly stop the production of ATP by aerobic respiration, as indicated by the sharp drop in the curve.

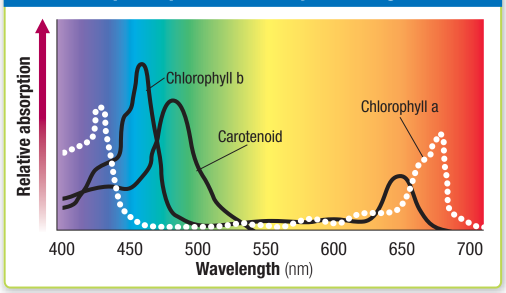
21. Define the role that oxygen plays in the electron transport chain.

22. Compare the efficiency of glycolysis with the efficiency of aerobic respiration.

Using Science Graphics

The graph shows the colors of light that three different photosynthetic pigments absorb. Use the graph to answer the following questions.

Absorption Spectra of Photosynthetic Pigments



23. According to the graph, chlorophyll *b* absorbs the most light at which wavelength?
- **a.** 430 nm
- **b.** 460 nm
- **c.** 530 nm
- **d.** 650 nm

24. Analyzing Data Why do the leaves of most plants appear green?

25. Recognizing Relationships How is the color of fall leaves related to the pigments in chloroplasts?

Critical Thinking

26. Evaluating Viewpoints State whether you think the following viewpoint can be supported, and justify your answer. "If Earth's early atmosphere had been rich in oxygen, photosynthetic organisms would not have been able to evolve."

27. Evaluating Differences Compare the energy flow in photosynthesis to the energy flow in cellular respiration.

28. Comparing Functions Explain why cellular respiration is more efficient when oxygen is present in cells than when oxygen is not present in cells.

29. Inferring Relationships What combination of environmental factors affects the rate of photosynthesis?

30. Evaluating Results Some yeast cells can use fermentation or cellular respiration. These yeast cells consume glucose much more slowly if oxygen is present than if oxygen is absent. Explain this observation.

31. Inferring Relationships How does cellular respiration depend on photosynthesis?

Writing Skills

32. Organizing Information Many plants have pores called *stomata* that take in CO_2 at night and release it during the day. These plants are called *CAM plants,* and some examples include cactuses and pineapple trees. Write a report about these types of plants, and summarize why this adaptation is an advantage for plants living in a hot, dry climate.

Alternative Assessment

33. Finding and Communicating Information Use the library or Internet resources to research how exercise physiologists regulate the diet and training of athletes. Find out how diets vary according to the needs of each athlete. Research the relationship between exercise and metabolism. Present your findings to your class.

34. Using Graphing Skills Create a poster that illustrates how an organism's metabolism is part of Earth's carbon cycle. Make drawings, create images on a computer, or use photos from magazines or online resources to illustrate your poster. Display your poster in the classroom.

Explaining Key Ideas

16. Autotrophs make their own organic compounds, usually using energy harvested from the sun. Heterotrophs get organic compounds by consuming autotrophs or feeding off other organisms that have consumed autotrophs.

17. The primary source of energy for humans is autotrophs. However, the ultimate source of energy for all organisms is the sun.

18. Without ATP, the Calvin cycle would not function and photosynthesis would cease.

19. The rate of photosynthesis increases as light intensity increases until all the pigments in a chloroplast are being used. At the saturation point, the rate levels off because the pigments cannot absorb any more light.

20. In glycolysis, organic compounds are converted to pyruvate, producing a small amount of ATP. In aerobic respiration, pyruvate is broken down and a large amount of ATP is formed.

21. Oxygen is the final electron acceptor at the end of electron transport.

22. Glycolysis alone can net 2 ATP molecules. Aerobic respiration is more efficient, producing up to 36 molecules of ATP.

Interpreting Graphics

23. b

24. Chlorophyll is the most abundant pigment in most plants. Chlorophyll absorbs mostly blue and red light and reflects green and yellow light.

25. When chlorophyll fades in the fall, the colors of the carotenoids (yellow, orange, and red) are exposed.

Critical Thinking

26. Students should acknowledge that photosynthetic organisms today carry out photosynthesis in the presence of oxygen.

27. Energy from the sun excites electrons in the pigments of the thylakoid membranes. Excited electrons are passed along the electron transport chain, setting up a concentration gradient of hydrogen ions. The gradient is used to make ATP. The process is similar in cellular respiration, but NADH is the original source of electrons, and the initial energy source is glucose rather than the sun.

28. If oxygen is present, aerobic respiration can occur. Aerobic respiration produces much more ATP than anaerobic processes.

29. Factors include light intensity, water availability, carbon dioxide concentration, and temperature.

30. Fermentation is a much less efficient process than aerobic respiration, and yeast cells must consume more glucose when O_2 is absent in order to make the amount of ATP they need for survival.

31. Photosynthesis supplies both the organic compounds and the oxygen that are used in aerobic respiration.

Writing Skills

32. CAM and C_4 plants have an advantage over C_3 plants in hot, dry conditions because they are adapted for taking up CO_2 while minimizing water loss through evaporation.

Alternative Assessment

33. Diet depends on the energy requirements of the athlete's sport. Some sports, such as weight lifting, involve mainly anaerobic metabolism. Others, such as jogging and swimming, involve aerobic respiration.

34. Students should include examples of autotrophs and heterotrophs, and should illustrate the processes of photosynthesis and cellular respiration.

Chapter 9 Standardized Test Prep

TEST TIP If you come upon a word that you do not know, try to identify its prefix, suffix, or root. Sometimes, knowing even one part of the word will help you answer the question.

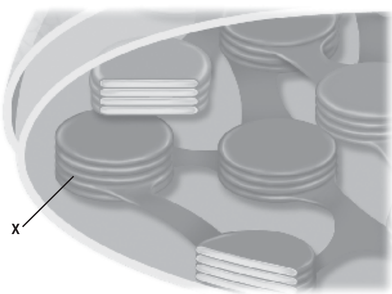
Science Concepts

1. What pigment causes a plant to look green?
- **A** NADH
- **B** NAPH
- **C** carotenoid
- **D** chlorophyll

2. What is the product of the electron transport chains of photosynthesis?
- **F** water
- **G** glucose
- **H** pyruvate
- **J** ATP and NADPH

3. The oxygen that is produced during photosynthesis comes directly from the
- **A** absorption of light.
- **B** mitochondrial membranes.
- **C** splitting of water molecules.
- **D** splitting of carbon dioxide molecules.

Use the diagram of a chloroplast to answer the following question.



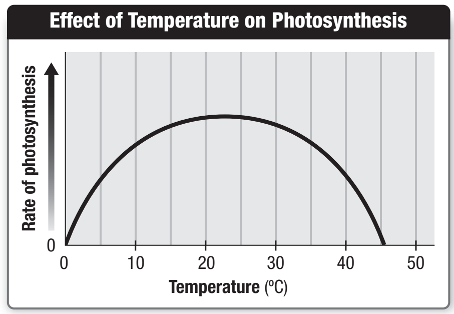
4. Which of the following correctly identifies the structure marked *X* and the activities that take place there?
- **F** stroma—Calvin cycle
- **G** thylakoid—Calvin cycle
- **H** stroma—light reactions
- **J** thylakoid—light reactions

5. Which of the following is involved in the aerobic part of cellular respiration?
- **A** ATP
- **B** glycolysis
- **C** lactic acid
- **D** fermentation

6. Which of the following is *not* a product of the Krebs cycle?
- **F** CO_2
- **G** ATP
- **H** $FADH_2$
- **J** ethyl alcohol

Using Science Graphics

The graph shows data on photosynthesis in one type of plant. Use the graph and your knowledge of science to answer the following question.



7. Which statement is supported by the data?
- **A** Photosynthesis does not occur at 0 °C.
- **B** The rate of photosynthesis at 40 °C is greater than the rate at 20 °C.
- **C** The optimum temperature for photosynthesis is approximately 46 °C.
- **D** The rate of photosynthesis increases as temperature increases from 25 °C to 30 °C.

Writing Skills

8. Short Response The inner membrane of a mitochondrion is folded. These folds are called *cristae.* How might cellular respiration be different if the inner mitochondrial membrane were not folded?

Answers

1. D **2.** J **3.** C
4. J **5.** A **6.** J
7. A
8. The cristae increase the surface area of the inner wall of the mitochondria, which allows more electron transport chain pathways and ATP synthase. Thus, the rate of cellular respiration is increased.

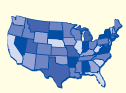
TEST DOCTOR

Question 4 Students must know the structure of the chloroplast and the processes that occur there. Choices **F** and **H** are incorrect because the X points to the thylakoid. Choice **G** is incorrect because the Calvin cycle is not a thylakoid process. Choice **J** is correct.

Question 5 Students must recognize that glycolysis precedes aerobic respiration. Choices **A, C,** and **D** are all incorrect because these items are all part of aerobic respiration. Choice **B** is correct. Glycolysis produces pyruvate, which is used to start the aerobic part of cellular respiration.

Question 7 Students must be able to interpret the data trends on the graph. Choice **A** is correct. The rate of photosynthesis at 0°C is zero. Choice **B** is incorrect because the rate of photosynthesis is less at 40°C than at 20°C. Choice **C** is incorrect because the optimum temperature (highest peak in the curve) occurs between 20°C and 25°C. Choice **D** is incorrect because the rate of photosynthesis is falling between 25°C and 30°C.

State Resources



For specific resources for your state, visit go.hrw.com and type in the keyword **HSHSTR**.

Test Practice with Guided Reading Development