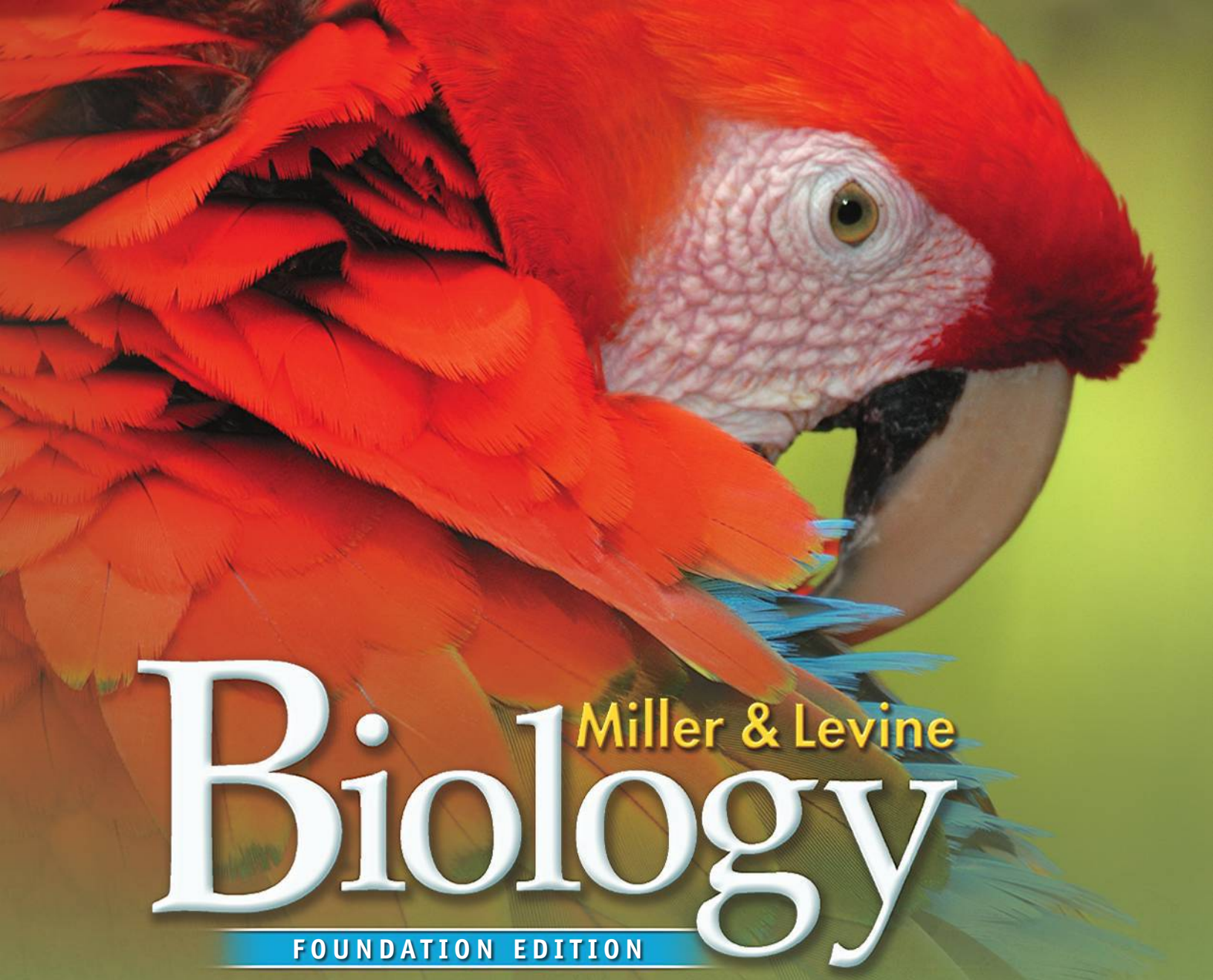

Miller & Levine Biology

FOUNDATION EDITION

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Providence, Rhode Island

Joseph S. Levine, Ph.D.
Science Writer and Producer
Concord, Massachusetts

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Teacher's Foundation Edition

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Study Workbook A, Teacher's Edition

Study Workbook B: Reading Foundations

Study Workbook B: Reading Foundations, Teacher's Edition

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Laboratory Manual A, Teacher's Edition

Laboratory Manual B: Skill Foundations

Laboratory Manual B: Skill Foundations, Teacher's Edition

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Teacher's ELL Handbook

Multilingual Glossary

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About the Authors

Kenneth R. Miller grew up in Rahway, New Jersey, attended the local public schools, and graduated from Rahway High School in 1966. Miller attended Brown University on a scholarship and graduated with honors. He was awarded a National Defense Education Act fellowship for graduate study, and earned his Ph.D. in Biology at the University of Colorado. Miller is professor of Biology at Brown University in Providence, Rhode Island, where he teaches courses in general biology and cell biology.

Miller's research specialty is the structure of biological membranes. He has published more than 70 research papers in journals such as *CELL*, *Nature*, and *Scientific American*. He has also written the popular trade books *Finding Darwin's God* and *Only a Theory*. He is a fellow of the American Association for the Advancement of Science.

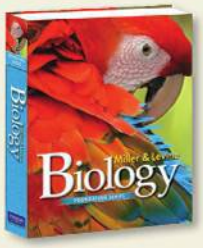
Miller lives with his wife, Jody, on a small farm in Rehoboth, Massachusetts. He is the father of two daughters, one a wildlife biologist and the other a high-school history teacher. He swims competitively in the masters' swimming program and umpires high school and collegiate softball.

Joseph S. Levine was born in Mount Vernon, New York, where he attended public schools. He earned a B.S. in Biology at Tufts University, a master's degree from the Boston University Marine Program, and a Ph.D. at Harvard University. His research has been published in scientific journals ranging from *Science* to *Scientific American*, and in several academic books. He has taught introductory biology, ecology, marine biology, neurobiology, and coral reef biology at Boston College and in the Boston University Marine Program. He has also co-taught a field biology course for high-school teachers entitled "Rainforests and Reefs" at the Organization for Tropical Studies in Costa Rica.

After receiving a Macy Fellowship in Science Broadcast Journalism at WGBH-TV, Levine dedicated himself to improving public understanding of science. His popular scientific writing has appeared in five trade books and in magazines such as *Smithsonian*, *GEO*, and *Natural History*. He has produced science features for National Public Radio and has designed exhibit programs for state aquarium projects in Texas, New Jersey, and Florida. Since 1987, Levine has served as scientific advisor at WGBH, where he worked on NOVA programs including *Judgment Day*, and on projects including the OMNI-MAX films *Cocos: Island of Sharks* and *Coral Reef Adventure*. He also served as science editor for the PBS series *The Secret of Life* and *The Evolution Project*.

Levine and his family live in Concord, Massachusetts, a short distance from Thoreau's Walden Pond.

Build a Solid Foundation



The Foundation Edition of *Miller & Levine Biology* is a new type of program. It offers the same content as *Miller & Levine Biology* made more accessible with:

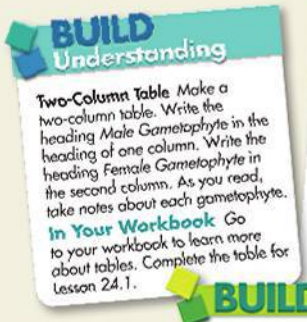
- **Embedded reading support**
- **Inquiry** activities that promote scientific thinking
- **Engaging visuals** that enhance instruction
- **Adapted ancillary support**
- **Digital instruction for the next-generation,** built for 21st Century learners

Reading Foundations

The Foundation Edition provides enhanced reading support with embedded reading strategies to make content more accessible.

Foundations for Learning are activities that feature manipulatives you can use to organize key concepts as you read a chapter.

Build Understanding provides suggestions on how to use graphic organizers as a framework for learning.



Build Vocabulary boxes highlight academic and scientific vocabulary from the chapter.

Build Connections are chapter features that help you create a connection between Big Ideas, putting science in a real-world context tied to a clear and easy-to-follow graphic.

Visuals Enhance Instruction

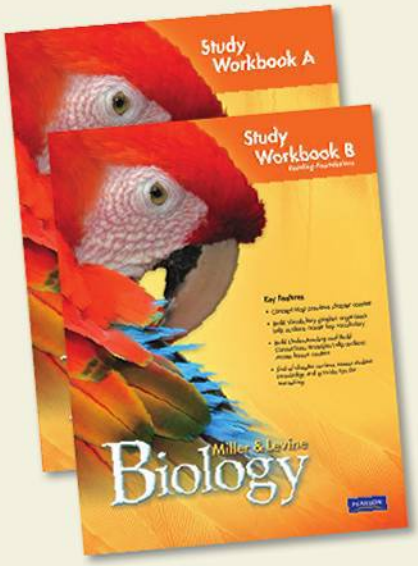
Stunning instructional visuals throughout each chapter offer a unique way to see what science looks like.

Visual analogies offer a way to relate key concepts to things you may see in your daily life. Visual summaries tie together the key concepts in a clear and easy-to-follow graphic. The magazine-style Visual Guide to the Diversity of Life provides a unique way to explore Earth's major organisms with key characteristics, habitats, behaviors, and other important facts.

Student Support Ensures Success

Biology is not a "one-size-fits-all" subject. *Miller & Levine Biology* provides content in ways that fit your unique learning style. The *Foundation* program offers workbooks that are written at an accessible reading level and work hand-in-hand with the *Foundation* Student Edition to help provide extra support to ensure content mastery. The accompanying ELL handbook also provides support for ELL classrooms.

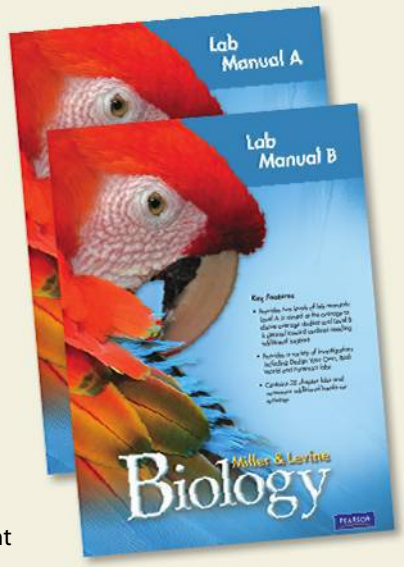
The *Foundation Edition* supports all students with 2 levels of resources.



Study Workbook B

The adapted Study Workbook for the *Foundation Edition* of *Miller & Levine Biology* will help you:

- preview a chapter
- work with the key vocabulary
- practice strategies for learning the content
- review for chapter and unit tests
- learn strategies for taking standardized tests



Lab Manual B

The adapted Lab Manual provides connections from the text to help you conduct lab experiments. You are encouraged to apply concepts, analyze data, and draw conclusions from lab activities. The *Extend Your Inquiry* feature encourages you to consider concepts outside of the step-by-step laboratory process.

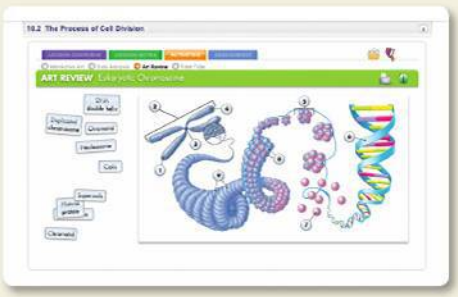
Biology.com—Your Online Habitat for Learning

Featuring the latest in instructional technology, Biology.com is an engaging program that brings biology concepts to life. Visual, interactive, and differentiated components help reinforce content and provide a broad understanding of scientific concepts.

Biology.com offers:

For Students:

- Complete *Foundation* Student Edition with audio helps you read along online
- Interactive visuals, tutorials, and simulations help you build connections as concepts come alive online.
- Scaffolded self-assessment prepares you for content mastery and end–of–course testing.



For Teachers:

- Lesson planner with leveled activities crafts lessons to support all levels of students.
- Lesson overview presentations help present the Big Ideas of each lesson
- Comprehensive, auto-graded assessment and remediation for different levels of students
- Editable worksheets that allow teachers to cater their lessons to your classroom's needs

Consultants/Reviewers

Grant Wiggins, Ed.D. is a co-author of the *Understanding by Design Handbook.* His approach to instructional design provides teachers with a disciplined way of thinking about curriculum design, assessment, and instruction that moves teaching from covering content to ensuring understanding.

Big idea Big Ideas are one of the core components of the Understanding by Design approach in *Miller & Levine Biology.* Big Ideas, such as the Cellular Basis of Life, establish a conceptual framework for the program. Each chapter in the Student Edition provides opportunities to link back to the Big Ideas. Since Understanding by Design is by nature a teaching tool, additional applications of this philosophy can be found in the Teacher's Edition.

The Association for Supervision of Curriculum Development (ASCD), publisher of the "Understanding by Design Handbook" co-authored by Grant Wiggins and registered owner of the trademark "Understanding by Design", has not authorized, approved or sponsored this work and is in no way affiliated with Pearson or its products.

Jim Cummins is Professor and Canada Research Chair in the Curriculum, Teaching and Learning department at the Ontario Institute for Studies in Education at the University of Toronto. His research focuses on literacy development in multilingual schools and the role of technology in promoting language and literacy development.

Program materials for *Miller & Levine Biology* incorporate research-based essential principles using Dr. Cummins's Into/Through/Beyond structure. You will find ample support for ELL instruction in the Teacher's Edition, Teacher's ELL Handbook, Multilingual Glossary, and Spanish components offered with this program.

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Contents

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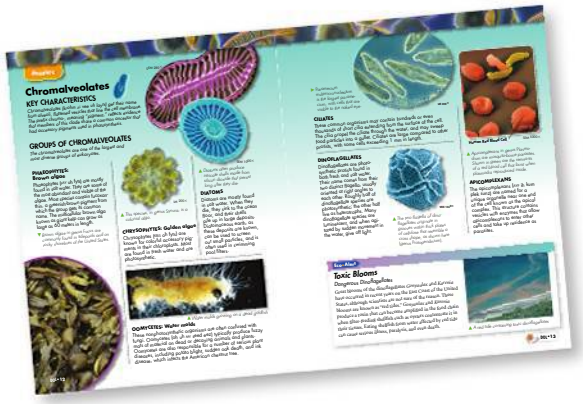


Appendix A: Science Skills

Appendix B: Lab Skills

Labs and Activities

INQUIRY into Scientific Thinking

Labs and Activities *(continued)*

Design Your Own Lab

Forensics Lab

Real-World Lab

Skills Lab

BUILD Connections with Visual Analogies

Dear Student:

Welcome to our world—the endlessly fascinating world of biology.

I can guess what some of you are thinking right now. "Fascinating? Yeah, right. Totally." Well, give us—and biology—a chance to show you that the study of the natural world really is more exciting, more fascinating, and more important to you personally than you've ever realized. In fact, biology is more important to our daily lives today than it has ever been.

Why? Three words: "We are one." This isn't meant in a "touchy-feely" or "New Age" way. "We" includes all forms of life on Earth. And "are one" means that all of us are tied together more tightly, in more different ways, than anyone imagined until recently.

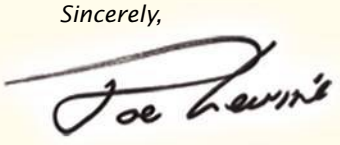
Both our "hardware" (body structures) and our "software" (genetic instructions and biochemical processes that program body functions) are incredibly similar to those of all other living things. Genetic instructions in our bodies are written in the same universal code as instructions in bacteria and palm trees. As biologists "read" and study that code, they find astonishingly similar processes in all of us. That's why medical researchers can learn about human diseases that may strike you or your family by studying not only apes and pigs and mice, but even yeasts. We are one on the molecular level.

All organisms interact with one another and with the environment to weave our planet's web of life. Organisms make rain forests and coral reefs, prairies and swamps—and farms and cities. We interact, too, with the winds and ocean currents that tie our planet together. Human activity is changing local and global environments in ways that we still don't understand . . . and that affect our ability to produce food and protect ourselves from diseases. We are one ecologically with the rest of life on Earth.

All organisms evolve over time, adapting to their surroundings. If humans alter the environment, other organisms respond to that change. When we use antibiotics against bacteria, they develop resistance to our drugs. If we use pesticides against insects, they become immune to our poisons. We are one in our ability to evolve over time.

Those are the kinds of connections you will find in this book. Microscopic. Enormous. Amusing. Threatening. But always fascinating. That's why—no matter where you start off in your attitude about biology—we think you are in for some surprises!

Sincerely,



Dear Student,

Biology is one of the subjects you're going to study this year, but I hope you'll realize from the very first pages of this book that biology is a lot more than just a "subject." Biology is what makes an eagle fly, a flower bloom, or a caterpillar turn into a butterfly. It's the study of ourselves—of how our bodies grow and change and respond to the outside world, and it's the study of our planet, a world transformed by the actions of living things. Of course, you might have known some of this already. But there's something more—you might call it a "secret" that makes biology unique.

That secret is that you've come along at just the right time. In all of human history, there has never been a moment like the present, a time when we stood so close to the threshold of answering the most fundamental questions about the nature of life. You belong to the first generation of students who can read the human genome almost as your parents might have read a book or a newspaper. You are the first students who will grow up in a world that has a chance to use that information for the benefit of humanity, and you are the very first to bear the burden of using that knowledge wisely.

If all of this seems like heavy stuff, it is. But there is another reason we wrote this book, and we hope that is not a secret at all. Science is fun! Biologists aren't a bunch of serious, grim-faced, middle-aged folks in lab coats who think of nothing but work. In fact, most of the people we know in science would tell you honestly, with broad grins on their faces, that they have the best jobs in the world. They would say there's nothing that compares to the excitement of doing scientific work, and that the beauty and variety of life make every day a new adventure.

We agree, and we hope that you'll keep something in mind as you begin the study of biology. You don't need a lab coat or a degree or a laboratory to be a scientist. What you do need is an inquiring mind, the patience to look at nature carefully, and the willingness to figure things out. We've filled this book with some of the latest and most important discoveries about living things, but we hope we've also filled it with something else: our wonder, our amazement, and our sheer delight in the variety of life itself. Come on in, and enjoy the journey!

Sincerely,

Ken Miller

The Nature of Life

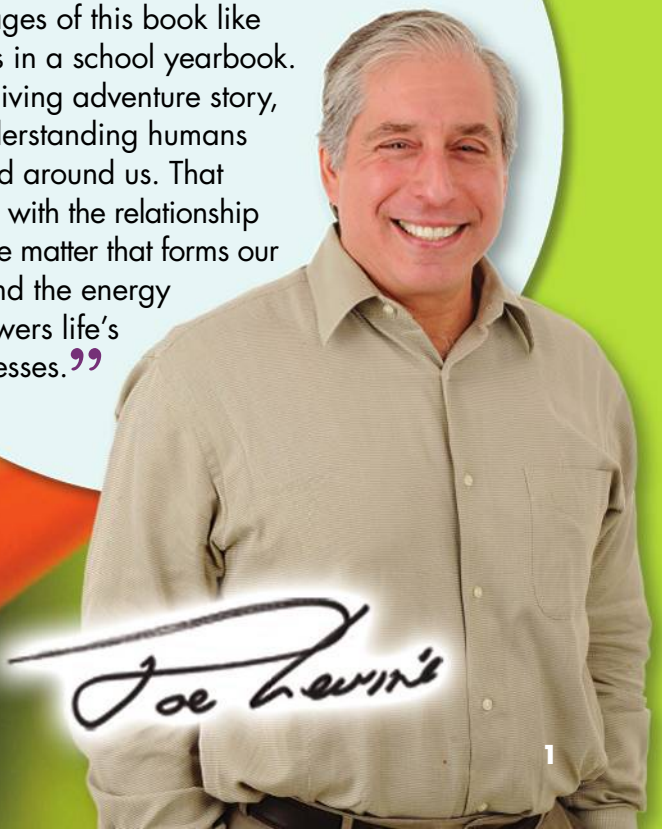
UNIT 1

Chapters

INTRODUCE the Big ideas

- **Science as a Way of Knowing**
- **Matter and Energy**

"Science is 'a way of knowing'—a way of explaining the natural world through observations, questions, and experiments. But science isn't just dry old data, pressed between pages of this book like prom flowers in a school yearbook. Science is a living adventure story, aimed at understanding humans and the world around us. That story begins with the relationship between the matter that forms our bodies and the energy that powers life's processes."



Joe Levine

1 The Science of Biology

Big idea

Science as a Way of Knowing

Q: What role does science play in the study of life?

BIOLOGY.com Search Chapter 1 GO • Flash Cards

INSIDE:

Paleontologists study ancient life. These students at the Academy of Natural Sciences in Philadelphia are working in the dinosaur lab. By using scientific skills such as observation and inference, scientists can learn how ancient animals lived.

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

HEIGHT BY PRESCRIPTION

A doctor gives a shot of a powerful chemical to an eight-year-old boy named David. This boy is perfectly healthy. He shows no signs of being sick. The "problem" that he is being treated for is very common. He is short for his age.

The chemical David is being given is human growth hormone, or HGH. HGH, together with genes and diet, controls growth during childhood. Some people produce little or no HGH. These people are extremely short and may have other health problems. But David has a normal amount of HGH. He is short because his parents are both healthy, short people.

But if David isn't sick, why does his doctor prescribe HGH? Where does HGH come from? Is it safe? And what does its use in David's case say about science and society?

Read for Mystery Clues As you read this chapter, look for clues about the nature of science, the role of technology in our modern world, and the relationship between science and society. Then, solve the mystery.

FOUNDATIONS for Learning

All living things share certain characteristics. Biology is the study of these characteristics. Before you read the chapter, make an Inspired Shape Tree. Your tree should have a trunk and eight branches. Write "Characteristics of Living Things" on the trunk. Then, as you read Lesson 3, describe a different characteristic on each branch. At the end of the chapter are two activities that use your tree to help answer the question: What role does science play in the study of life?

1.1 What Is Science?

Key Questions

- ***What are the goals of science?***
- ***What are the parts of scientific methodology?***

BUILD Understanding

Flowchart As you read, create a flowchart showing the steps scientists use to answer questions about the natural world.

In Your Workbook Go to your workbook to learn more about making a flowchart.

What Science Is and Is Not

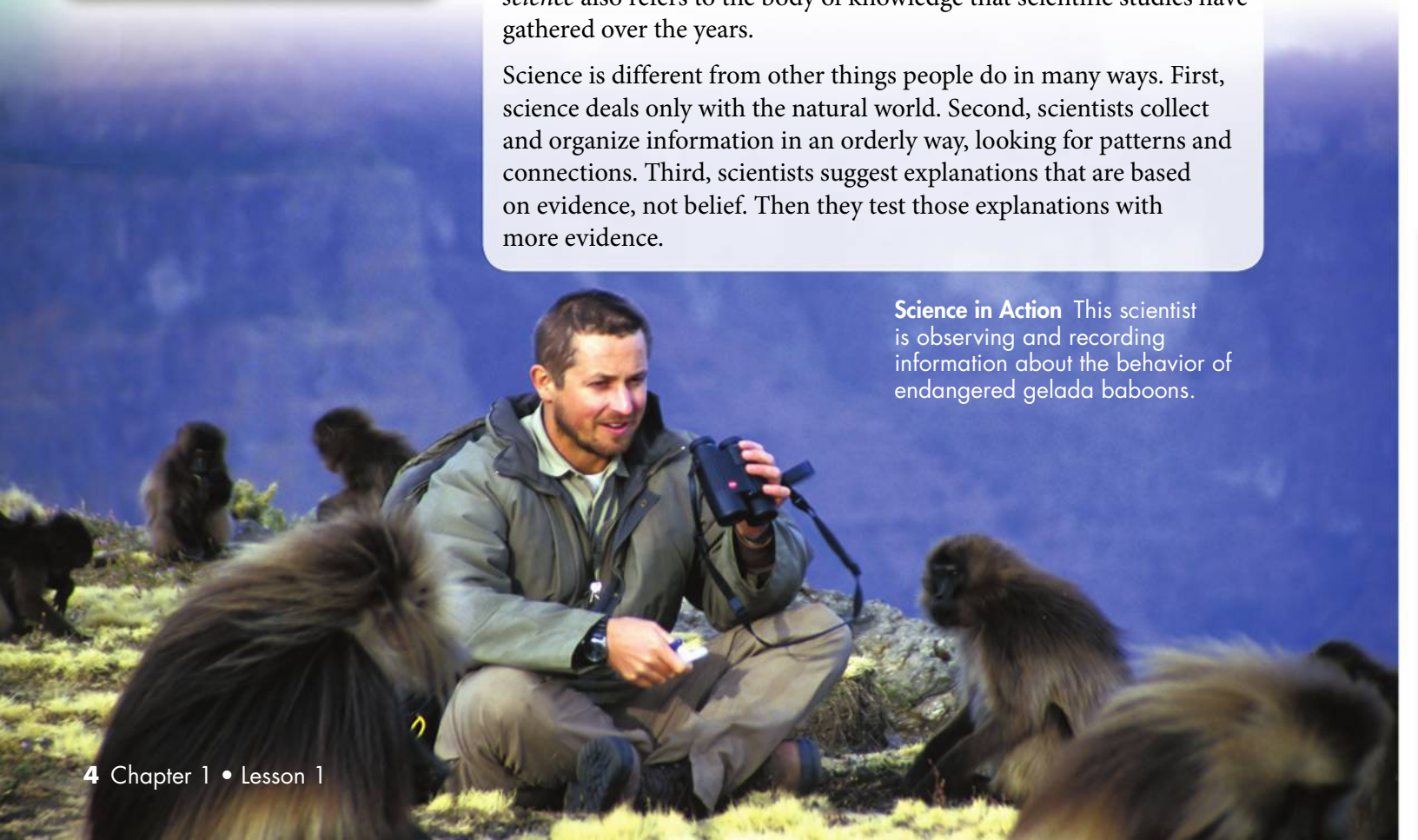
Where did plants and animals come from? How did I come to be? People have tried to answer those questions in different ways. Some ways of explaining the world have stayed the same over time. Science, however, is always changing.

This book has lots of facts and ideas about living things. But biology, or any science, is not just a collection of never-changing facts. Some of the facts in this book will change soon—if they have not changed already! What's more, science is not a lot of unchanging ideas about the world. Scientific ideas are open to testing, discussion, and change. If science is neither a list of facts nor a lot of unchanging ideas, what is it?

Science as a Way of Knowing

Science is an organized way of gathering and analyzing evidence about the natural world. It is a way of looking, a way of thinking, and "a way of knowing" about the world. In other words, science is a *process*, not a "thing." The word *science* also refers to the body of knowledge that scientific studies have gathered over the years.

Science is different from other things people do in many ways. First, science deals only with the natural world. Second, scientists collect and organize information in an orderly way, looking for patterns and connections. Third, scientists suggest explanations that are based on evidence, not belief. Then they test those explanations with more evidence.



Science in Action This scientist is observing and recording information about the behavior of endangered gelada baboons.

The Goals of Science From a scientific view, objects in the universe, and all interactions among those objects, are ruled by natural laws. One goal of science is to use an understanding of those laws to give natural explanations for events in the natural world. Science also aims to use those explanations to understand patterns in nature and to make useful predictions about natural events.

Key Question What are the goals of science?

The goals of science are to give explanations for natural events, to understand patterns, and to make predictions.

Science, Change, and Uncertainty Scientists know a lot about nature. Yet, much of nature remains a mystery because science never stands still. This constant change does not mean science has failed. It shows that science is always improving.

Science rarely "proves" anything in absolute terms. Scientists aim for the best understanding that can be found. Uncertainty is a part of science and is part of what makes science exciting!

Scientific Methodology

There isn't any single "scientific method." But there is a general style of investigation that can be called scientific methodology. The parts of scientific methodology are described below.

Observing and Asking Questions Scientific studies begin with **observation,** the act of noticing and describing what is happening in an orderly way. Observation leads to new questions.

Inferring and Forming a Hypothesis After asking questions, scientists use further observations to make inferences. An inference is an idea based on what is already known. Inference, along with imagination, can lead to a hypothesis. A **hypothesis** is a scientific explanation for a set of observations that can be tested.

BUILD Vocabulary

science
an organized way of gathering and analyzing evidence about the natural world

observation
a process of noticing and describing events or processes in a careful, orderly way

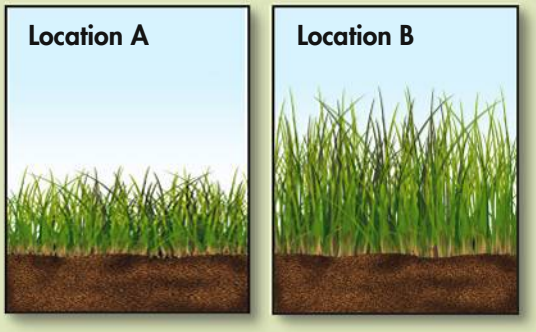
hypothesis
a possible explanation for a set of observations or a possible answer to a scientific question

WORD ORIGINS

The word *science* comes from the Latin word *scientia,* which means "knowledge." Science represents knowledge that has been gathered over time.

Salt Marsh Experiment Scientists made observations about a salt marsh. Then they used scientific methodology to answer the questions that came from their observations.

Observing and Asking Questions



Scientists observed that marsh grass grows taller in some places than others. This observation led to a question: *Why do marsh grasses grow to different heights in different places?*

Inferring and Hypothesizing

The scientists inferred that something limits grass growth in some places. Temperature, sunlight, water, or nutrients could cause the difference. Based on their knowledge of salt marshes, they proposed a hypothesis: *Marsh grass growth is limited by available nitrogen.*

BUILD Vocabulary

controlled experiment
an experiment in which only one variable is changed

control group
the group in an experiment that is exposed to the same conditions as the experimental group except for one independent variable

data
evidence; information gathered from observations

RELATED WORD FORMS

The word *data* is plural for *datum*. To help you remember that *data* is plural, you can think of data as being a lot of information and datum as just one piece of information.

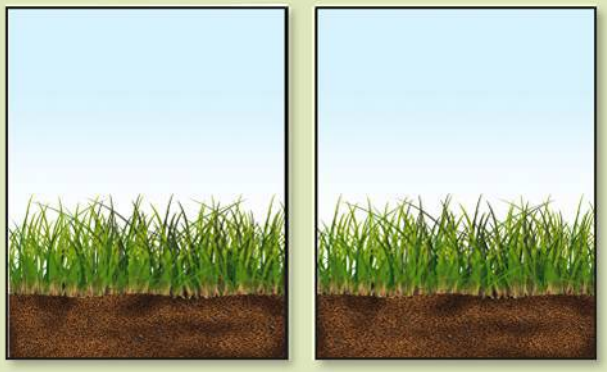
Designing Controlled Experiments Testing a hypothesis often involves an experiment that keeps track of variables, or the things that can change. A few examples of variables include temperature, light, and time. Whenever possible, a hypothesis should be tested by an experiment in which only one variable is changed. All other variables should be kept unchanged, or controlled. An experiment in which only one variable is changed is called a **controlled experiment.**

▶ ***Controlling Variables*** Why are variables controlled? The reason is that if more than one variable is changed in an experiment, scientists cannot easily tell which variable caused the results. The variable that is changed is called the independent variable. The variable that is observed and that changes because of modifications to the independent variable is called the dependent variable.

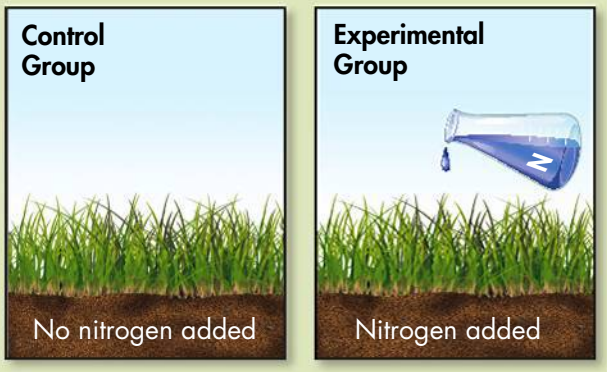
▶ ***Control and Experimental Groups*** An experiment is usually divided into control and experimental groups. A **control group** is treated the same as the experimental group except for one independent variable. Scientists often repeat their experiments several times to see if they get the same results. This process is called replicating the experiment. So, scientists set up several sets of control and experimental groups, rather than just a single pair.

Collecting and Analyzing Data Scientists make detailed records of experimental observations by gathering information called **data.** There are two main kinds of data. Quantitative data are numbers found by counting or measuring. Qualitative data describe things that cannot be counted.

Designing Controlled Experiments



The scientists selected areas that had similar numbers of plants and similar soil type, water supply, and height above the water level. The areas were divided into control and experimental groups.



The scientists added nitrogen fertilizer (the independent variable) to the experimental groups. They then observed the growth of marsh grass (the dependent variable) in both experimental and control groups.

▶ ***Research Tools*** Scientists pick the right tools for collecting and analyzing data. The tools may be simple, such as metersticks and calculators, or they may be complex, such as computers or robots. Charts and graphs are also tools that help scientists organize data.

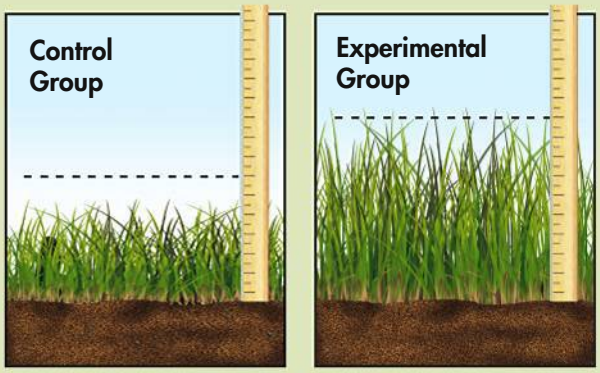
▶ ***Sources of Error*** Scientists must avoid errors in data collection and analysis. Errors may happen when using tools. Tools have limited accuracy or can be read incorrectly. Data analysis and decisions about sample size must be carried out carefully to avoid errors. Sometimes experimental and control groups are very large. Why? The reason is because there are always differences among subjects in the groups. The larger the sample size, the more sure scientists are about their data analysis.

Drawing Conclusions Scientists use data to support or refute the hypothesis, to change the hypothesis, or to draw a valid conclusion. Hypotheses are often not shown to be completely right or wrong by an experiment. Rather, the data may show that the scientists have the right idea but are wrong about a few things. In that case, scientists change the first hypothesis, make new predictions, and design new experiments.

Key Question What are the seven parts of scientific methodology?

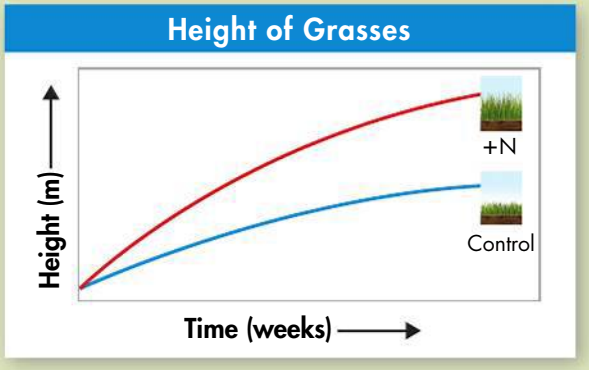
Scientific methodology involves observing and asking questions, making inferences and forming hypotheses, doing controlled experiments, collecting and analyzing data, and drawing conclusions.

Collecting and Analyzing Data

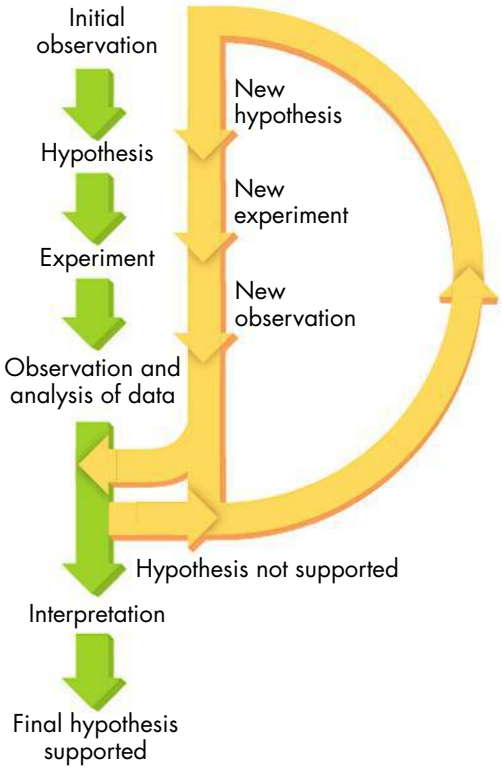


The scientists sampled all the areas during the growing season. They measured growth rates and plant sizes, and analyzed the chemicals in the leaves.

Drawing Conclusions



Data from all the areas were compared and evaluated. Data confirmed that marsh grasses with added nitrogen grow taller and larger than marsh grasses without added nitrogen. The hypothesis and its predictions were supported.



Revising Hypotheses During an investigation, scientists may have to change their hypotheses and redo experiments several times.

When Experiments Are Not Possible It is not always possible to test a hypothesis with an experiment. In some cases, scientists come up with hypotheses that can be tested by observations. For example, scientists who study how animals behave might want to learn how animal groups act in the wild. Studying this kind of natural behavior means that the scientists must go into the wild and watch the animals without bothering them. When scientists analyze data from these observations, they may come up with hypotheses that can be tested in different ways.

Sometimes, ethics keeps scientists from doing certain kinds of experiments. Ethics are beliefs about what is wrong or right. Some experiments on people are not ethical to do. For example, suppose that some scientists think that a chemical causes cancer in people who breathe it in. The scientists cannot make people breathe the chemical to see if they are correct! Instead, the scientists search for people who have already breathed in the chemical. Then, the scientists study people who have not breathed in the chemical.

When experiments are not possible, scientists still try to control as many variables as possible. They might not use people in their study who have serious health problems or known genetic conditions. Medical scientists often study large groups of subjects so that genetic differences between people do not give results that may not be correct.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. If you measure the width of this book with a ruler, you are collecting _____.
2. A good experiment should have an experimental group and a(n) _____.
3. A(n) _____ is a possible explanation for a set of observations.

Critical Thinking

4. **Explain** List the goals of science.
5. **Explain** Why are hypotheses so important to controlled experiments?
6. **Write to Learn** Answer the first clue of the mystery. Be sure your answer identifies the independent and dependent variables.

MYSTERY CLUE

Describe a controlled experiment that would test the hypothesis that extra HGH helps children grow taller. What ethical issues can you imagine in actually carrying out such a study? (Hint: See p. 6.)

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1.2 Science in Context

Exploration and Discovery: Where Ideas Come From

Scientific methodology is the heart of science. But that "heart" is only part of the full "body" of science. The full body of science is shown in the Process of Science at the bottom of this page. Part of science is exploration and discovery. How do exploration and discovery start? They often begin with scientific attitudes, practical problems, and new technology.

Scientific Attitudes Good scientists share scientific attitudes that lead them to exploration and discovery.

▶ ***Curiosity*** Scientists are curious and ask questions about what they observe. Results from previous studies also raise curiosity and lead to new questions.

▶ ***Skepticism*** Scientists are skeptics, which means that they question existing ideas and hypotheses. They also do not believe ideas without evidence.

▶ ***Open-Mindedness*** Scientists must be open-minded. They must be willing to accept new ideas that they may not agree with.

▶ ***Creativity*** Scientists need to think creatively to design experiments that provide good data.

Key Question What scientific attitudes help make new ideas?
Curiosity, skepticism, open-mindedness, and creativity help scientists come up with new ideas.

Practical Problems Sometimes, ideas for scientific investigations come from practical problems. For example, people want cars that do not cause air pollution. Practical problems lead to questions, hypotheses, and experiments.

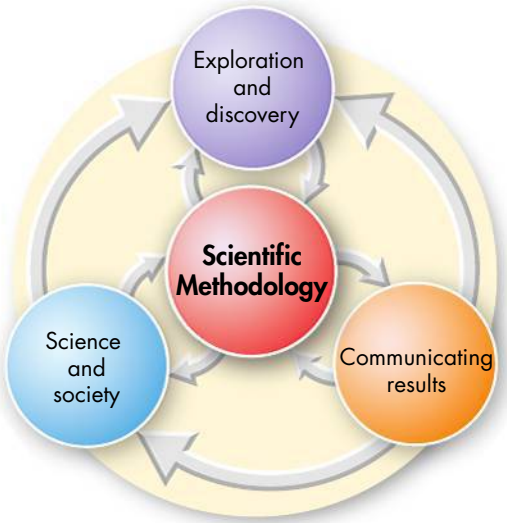
Key Questions

- ***What scientific attitudes help make new ideas?***
- ***Why is peer review important?***
- ***What is a scientific theory?***
- ***How are science and society related?***

BUILD Understanding

Previewing Visuals Before you read, study the figure on the last page of this section. As you read, use the figure to describe the role that science plays in society.

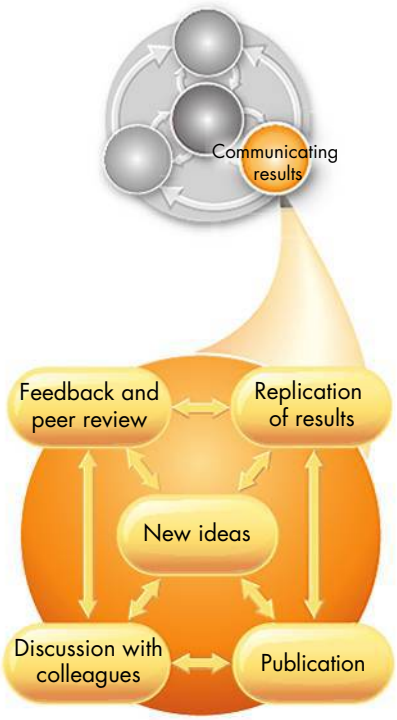
In Your Workbook Go to your workbook to learn more about previewing visuals.



The Process of Science The arrows show that the different parts of science are connected in many ways. So, the process of science is flexible, unpredictable, and always changing.

Exploration and Discovery Ideas in science can turn up in many ways—from curiosity to the need to solve a certain problem. Scientists often begin investigations by making observations, asking questions, talking to other scientists, and reading about other experiments.

Adapted from *Understanding Science*, UC Berkeley, Museum of Paleontology



Adapted from *Understanding Science*, UC Berkeley, Museum of Paleontology

Communicating Results Communication is an important part of science. Scientists look over one another's work to make sure it meets scientific standards. Results from one study may lead to new ideas and new studies.

The Role of Technology Technology, science, and society are closely linked. Discoveries in science may lead to new technologies. Those technologies, in turn, enable scientists to ask new questions or to gather data in new ways. Technology can also have big impacts on daily life. For instance, it is now possible to make vitamins, antibiotics, and hormones that before were only available naturally.

Communicating Results: Reviewing and Sharing Ideas

Data collection and analysis can take a long time. Scientists may work on a single study for months or even years. Then, the scientists communicate results to other scientists.

Peer Review Scientists share their findings with other scientists by publishing papers that go through peer review. In peer review, papers are reviewed by other scientists. These reviewers read papers looking for mistakes and other problems. Peer review does not make sure that a piece of work is correct, but it does make sure that the work meets standards set by the scientific community. Publishing peer-reviewed papers in journals lets scientists share ideas and review each other's work.

Sharing Knowledge and New Ideas How do new findings fit into what is already known about science? Perhaps the findings lead to new questions. Each of those questions could lead to new hypotheses and new controlled experiments.

Key Question Why is peer review important?
Publishing peer-reviewed papers in journals lets scientists share ideas and review each other's work.

INQUIRY into Scientific Thinking

Replicating Procedures

Scientists often repeat each other's experiments. They do this to make sure that the data and conclusions of the first scientist are correct. So, when scientists write papers to publish in journals, they must describe the procedures that they followed. The descriptions have to be good enough so that other scientists can repeat the first scientist's experiment.

1. Working with a partner behind a screen, arrange ten blocks into an unusual structure.
2. Write directions that others can use to build the same structure without seeing it.
3. Exchange directions with another team.
4. Build the other team's structure by following the directions.
5. Compare each new structure to the original. Identify which parts of the directions were clear and correct, and which parts were hard to understand or follow.

Analyze and Conclude

1. **Evaluate** How could you have written better directions?

2. **Infer** Why is it important that scientists write procedures that can be repeated?

In Your Workbook Get more help for this activity in your workbook.

Scientific Theories

In science, a **theory** is a well-tested explanation that accounts for a lot of observations and hypotheses and that lets scientists make good predictions. For example, Charles Darwin's early observations and hypotheses about change over time grew for years before he collected them into a theory of evolution by natural selection. Today, this theory is a central idea in biology.

A useful theory that has been tested and supported in many ways may become the most accepted view among scientists. But no theory is thought to be absolute truth. Science is always changing. As new evidence is found, a theory may be changed or replaced by a more useful explanation.

Key Question What is a scientific theory?

A scientific theory is a well-tested explanation that accounts for a lot of observations and hypotheses and that lets scientists make good predictions.

BUILD Vocabulary

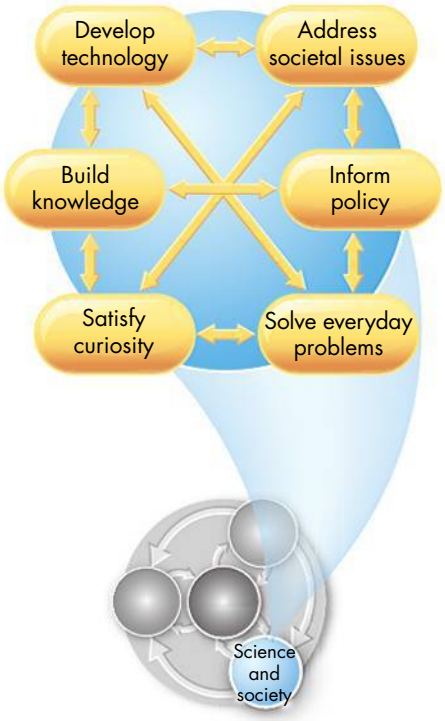
theory
a well-tested explanation that unifies a broad range of observations and hypotheses, and enables scientists to make accurate predictions about new situations

bias
a particular preference or point of view that is personal, rather than scientific

MULTIPLE MEANINGS

The word *theory* is used both in science and in everyday life. In everyday life, when you say, "I have a theory," you may mean, "I have a hunch." But in science, a theory is much stronger than a hunch—it is a well-tested explanation.

Adapted from *Understanding Science*, UC Berkeley, Museum of Paleontology



Science and Society Science can help society or change how people in society do things. But society also affects science. Problems and questions in society may lead scientists to do new experiments.

Science and Society

Many important questions can only be answered with the help of scientific information. But very few of these questions can be answered by science alone. These questions involve the society in which we live. Using science involves understanding its limitations and how it fits into society.

Science, Ethics, and Morality When scientists explain "why" something happens, their explanation is about only nature. Science does not include ethical or moral views. Scientists can try to explain what life is. But science cannot answer questions about why life exists or what the meaning of life is.

Avoiding Bias How science is used in society can be affected by bias. A **bias** is a certain preference or point of view that is personal, rather than scientific. Examples of biases include personal taste and liking one thing over another.

Scientists try to avoid bias. But scientific data can be used in the wrong way by people who want to prove a certain point. However, if enough of us understand science, we can help make sure that science is used in only helpful, correct ways.

Understanding and Using Science As you read this book, don't think of it as an encyclopedia. Don't memorize the scientific facts and ideas. Instead, try to understand how scientists developed those ideas. Understanding science will help you make decisions that also fit with society's values.

Key Question How are science and society related?
Using science involves understanding its limitations and how it fits into society.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete the sentence correctly.

1. A point of view that is personal rather than scientific is a _____.
2. Scientists can use a _____ to make good predictions.

Critical Thinking

3. **Explain** What does it mean to be skeptical? Why is skepticism a good quality in a scientist?
4. **Explain** Describe some of the limitations of science.

5. **Write to Learn** Write the answer to the second clue of the mystery.

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1.3 Studying Life

Characteristics of Living Things

Think about news stories that you have seen or heard. Bird flu spreads around the world killing thousand of birds and threatening an epidemic. People who use illegal drugs get permanent brain damage. These and many other stories are about biology—the study of living things. (The Greek word *bios* means "life," and *-logy* means "study of.")

Biology is the study of life. But what is life? What is the difference between living things and nonliving matter? It is not as simple as you might think to describe what makes something alive. No single characteristic is enough to describe a living thing. Also, some nonliving things share one or more traits with living things. For example, automobiles and clouds (which are not alive) move around. However, mushrooms and trees (which are alive) stay in one spot.

Despite these difficulties, we can list characteristics that most living things have in common. Living things are made up of basic units called cells, are based on a universal genetic code, obtain and use materials and energy, grow and develop, reproduce, respond to their environment, maintain a stable internal environment, and change over time.

Key Question What characteristics do all living things share?
Living things are made up of basic units called cells, are based on a universal genetic code, obtain and use materials and energy, grow and develop, reproduce, respond to their environment, maintain a stable internal environment, and change over time.

Key Questions

- ***What characteristics do all living things share?***
- ***What are the big ideas of biology?***
- ***How do different fields of biology differ in the way they study life?***
- ***Why is the metric system important in science?***

BUILD Understanding

Concept Map As you read, draw a concept map showing the big ideas in biology.

In Your Workbook Go to your workbook and finish the concept map for Lesson 1.3.

Is It Alive? The fish are clearly alive, but what about the colorful structure above them? Is it alive? Yes! It is an animal called elkhorn coral. Corals show all the characteristics of living things.

BUILD Connections

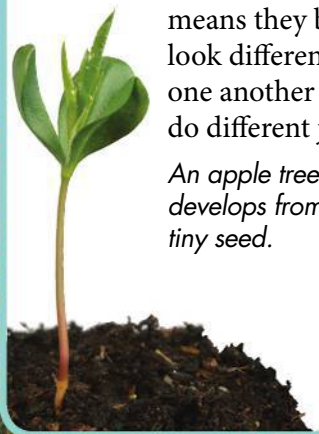
THE CHARACTERISTICS OF LIVING THINGS

Apple trees share certain characteristics with other living things. How are the apple tree and the grass growing below similar? How are they different?

Living things are based on a universal genetic code. All organisms store the information they need to live, grow, and reproduce in a genetic code written in a molecule called **DNA.** That information is copied and passed from parent to offspring. With a few small differences, life's genetic code is almost the same in every living thing on Earth.

The information in an apple tree's DNA directs all of the tree's life processes.

Living things grow and develop. Every organism has a certain pattern of growth and development. During development, a single fertilized egg divides again and again. As these cells divide, they differentiate, which means they begin to look different from one another and to do different jobs.



An apple tree develops from a tiny seed.

Living things respond to their environment. Organisms notice and react to stimuli from their environment. A **stimulus** is a signal to which a living thing reacts.

Some plants can produce poisons to ward off caterpillars that feed on its leaves.

Living things reproduce. All living things make new similar living things. Most plants and animals engage in sexual reproduction. In sexual reproduction, cells from two parents come together to form the first cell of a new living thing. Other living things reproduce through asexual reproduction, in which a single living thing makes offspring exactly the same as itself.

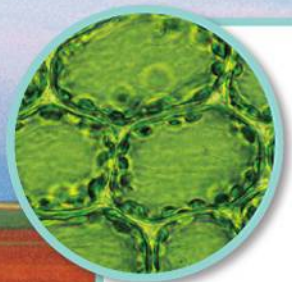
Flowers form as part of the apple tree's reproductive cycle.

Living things maintain a stable internal environment. All living things need to keep conditions inside themselves as constant as possible, even when conditions outside of them change. When conditions inside organisms are kept within certain limits, this is called **homeostasis.**

These cells help leaves control gases that enter and leave the plant. SEM 1200×

Living things get and use material and energy. All living things must take in materials and energy to grow, develop, and reproduce. The chemical reactions through which a living thing builds up or breaks down materials are called **metabolism.**

Different metabolic reactions happen in leaves.



Living things are made up of cells. Living things are made up of one or more cells—the smallest units considered fully alive. Cells can grow, respond to their surroundings, and reproduce. Even though cells are small, they are complex and very organized.

One branch of a tree is made up of millions of cells. LM 250×

Taken as a group, living things evolve. Over generations, groups of living things evolve, or change over time. Evolutionary change links all forms of life to a common origin more than 3.5 billion years ago. Evidence of this shared history is found in all parts of living things and fossils, from body parts to proteins to information in DNA.

Signs of one of the first land plants are preserved in rock over 400 million years old.

BUILD Vocabulary

biology
the scientific study of life

DNA
the genetic material that organisms inherit from their parents

stimulus
a signal to which an organism responds

homeostasis
the relatively constant internal physical and chemical conditions that organisms maintain

metabolism
the combination of chemical reactions through which an organism builds up or breaks down materials

biosphere
the part of Earth in which life exists, including land, water, and air or atmosphere

PREFIXES

The prefix *homeo-* means "the same" or "similar." Homeostasis is how the body keeps conditions inside the same at all times.

Big Ideas in Biology

All parts of biology are tied together by big ideas. These big ideas overlap and interlock with one another. They will come up again and again throughout the book. Many of these big ideas overlap with the characteristics of life or the nature of science.

Big idea **Cellular Basis of Life** Living things are made of cells. Many living things are made up of only a single cell; they are called unicellular organisms. Plants and animals are multicellular. Cells in multicellular organisms display many different sizes, shapes, and functions.

Big idea **Information and Heredity** Living things carry information written in a universal genetic code in their DNA. The information coded in DNA forms an unbroken chain that stretches back roughly 3.5 billion years. Yet, the DNA inside your cells right now can affect your future, such as your risk of getting cancer and the color of your children's hair.

Big idea **Matter and Energy** Life needs matter that serves as nutrients to build body parts and energy that fuels the body. Some living things, such as plants, get energy from sunlight and take up nutrients from air, water, and soil. Other living things, including most animals, eat plants or other animals to get both nutrients and energy. The need for matter and energy ties all living things on Earth together into a living web of relationships.

Big idea **Growth, Development, and Reproduction** All living things reproduce, which means that they make more individuals. Offspring are almost always smaller than adults, so they grow and develop as they mature.

Big idea **Homeostasis** Living things keep a fairly stable internal environment. For most organisms, any problems with homeostasis may have serious or deadly consequences.

Big idea **Evolution** Evolutionary change ties all forms of life to a common beginning more than 3.5 billion years ago. Evolution is the central organizing idea of all biology.

Different But Similar This colorful bird is different from the plant it is sitting on. Yet, the two living things are similar on the molecular level. Unity and diversity of life is a big idea in biology.

Big idea **Structure and Function** Each major group of living things has evolved its own set of body parts. These parts make certain functions possible. Living things have evolved into different forms as species have adapted to life in different places.

Big idea **Unity and Diversity of Life** Although life comes in a huge variety of forms, all living things are similar at the molecular level. All living things are made up of a common set of molecules, have DNA, and use proteins to build their body parts and carry out their functions. Evolutionary theory explains both this unity of life and its diversity.

Big idea **Interdependence in Nature** All forms of life on Earth are connected into a **biosphere,** which means "living planet." Within the biosphere, living things are linked to one another and to the land, water, and air around them. Relationships between living things and where they live depend on the cycling of matter and the flow of energy.

Big idea **Science as a Way of Knowing** Science is not a list of facts. The job of science is to use observations, questions, and experiments to explain the natural world. Good scientific research finds rules and patterns that can explain and predict at least some events in nature.

Key Question What are the big ideas of biology?
Biology's big ideas are the cellular basis of life; information and heredity; matter and energy; growth, development, and reproduction; homeostasis; evolution; structure and function; unity and diversity of life; interdependence in nature; and science as a way of knowing.

Fields of Biology

Biology is made up of many overlapping fields that use different tools to study life from the level of molecules to the whole planet. Here's a peek into a few of the many branches of biology.

Global Ecology The world is affected by everything that living things do. Global ecological studies using satellites and huge computers are letting us learn about people's global impact, which affects all life on Earth.

Biotechnology This field is based on the ability to read, write, and edit the genetic code. We may soon learn to correct or replace genes that cause diseases. But biotechnology also raises a lot of ethical, legal, and social questions.

Biotechnology This plant biologist is analyzing genetically modified rice plants.

Building the Tree of Life Biologists have found about 1.8 million different kinds of living things. Scientists want to use computers to gather what is known about all organisms to put all living things into a single "Tree of All Life."

Evolution of Diseases An entomologist, a person who studies insects, and other researchers inspect mosquito traps in Florida. Mosquitoes can transmit diseases to people.

Genomics and Molecular Biology A molecular biologist is analyzing a DNA sequence.

Ecology and Evolution of Diseases Over time, viruses, bacteria, and other organisms that cause disease evolve so that they still infect people, even as we try to fight them. Understanding how germs change and react to their surroundings is important for keeping people healthy.

Genomics and Molecular Biology Scientists are looking at the DNA of many different living things. Scientists analyze the data with powerful computers to learn about growth, development, and the history of life on Earth.

Key Question How do different fields of biology differ in the way they study life?
Biology is made up of many overlapping fields that use different tools to study life from the level of molecules to the whole planet.

Performing Biological Investigations

Scientists use a common system of measurement and practice safety when doing studies.

Scientific Measurement Most scientists use the metric system when gathering data and doing experiments. The metric system is a system of measurement in which units are based on multiples of 10. A revised version of the metric system is called the International System of Units, or SI. The metric system is easy to use because it's based on multiples of 10.

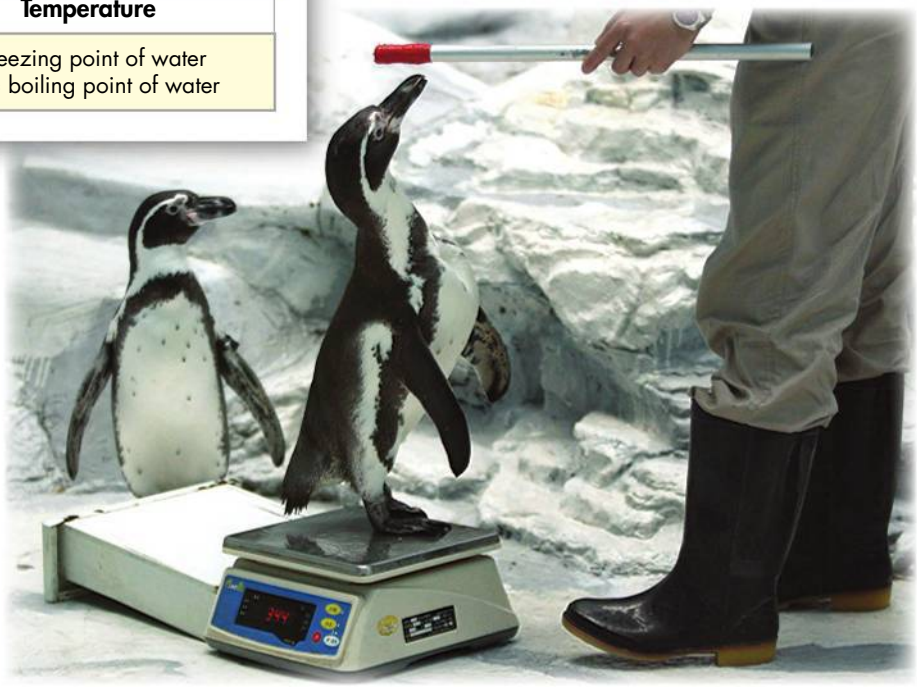
Safety Scientists are trained to be safe when doing investigations. Whenever you work in your biology lab, you must follow safety rules, too. Careful preparation is the key to staying safe while doing activities. Before doing any activity, be sure you understand the safety rules. Also, read all the steps in the activity and make sure that you understand them.

The most important safety rule is to always follow your teacher's instructions. You are responsible for your own safety and that of your teacher and classmates. If you are handling live animals, you are responsible for their safety, too.

Key Question Why is the metric system important in science?
Most scientists use the metric system when collecting data and performing experiments.

Common Metric Units

Length	Mass
1 meter (m) = 100 centimeters (cm) 1 meter = 1000 millimeters (mm) 1000 meters = 1 kilometer (km)	1 kilogram (kg) = 1000 grams (g) 1 gram = 1000 milligrams (mg) 1000 kilograms = 1 metric ton (t)
Volume	**Temperature**
1 liter (L) = 1000 milliliters (mL) 1 liter = 1000 cubic centimeters (cm^3)	0°C = freezing point of water 100°C = boiling point of water



The Metric System Scientists usually use the metric system in their work. These penguins have been trained to hop onto the scale to be weighed.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete the sentence correctly.

1. All the information that an animal needs to live is stored in its _____.
2. The part of Earth where living things are found is called the _____.
3. All the reactions by which a living thing builds up and breaks down matter is its _____.

Critical Thinking

4. **Applying Concepts** Suppose you feel hungry, so you reach for an apple in a fruit bowl. How do stimuli both outside and inside of your body lead you to take the apple?
5. **Relate Cause and Effect** Suppose that two scientists are doing an experiment using dangerous chemicals. How might their safety be affected by not using a common measurement?
6. **Write to Learn** Write the answer to the third clue of the mystery.

MYSTERY CLUE

What human values or biases are involved in the case of giving HGH to healthy children? What role does science play in this case?

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Pre-Lab: Using a Microscope to Estimate Size

Problem How can you use a microscope to estimate the size of an object?

Materials compound microscope, transparent 15-cm plastic ruler, prepared slide of plant root or stem, prepared slide of bacteria

Lab Manual Chapter 1 Lab

Skills Focus Observe, Measure, Calculate, Predict

Connect to the Big idea Science provides a way of knowing the world. The use of technology to gather data is a central part of modern science. In biology, the compound microscope is a vital tool. With a microscope, you can observe objects that are too tiny to see with the unaided eye. These objects include cells, which are the basis for all life.

In this lab, you will explore another important use of the microscope. You will use the microscope to estimate the size of cells.

Background Questions

a. Explain How did the invention of the microscope help scientists know the natural world?

b. Explain How can a microscope help a scientist use scientific methodology?

c. Infer List one important fact about life that scientists would not know without microscopes. *Hint:* Review the characteristics of living things.

Pre-Lab Questions

Preview the procedure in the lab manual.

1. Review Which lens provides more magnification—a low-power lens or a high-power lens?

2. Infer Which lens will provide the larger field of view—a low-power lens or a high-power lens?

3. Calculate Eight cells fit across a field of view of 160 µm. What is the width of each cell? MATH

4. Predict Which cell do you think will be larger, the plant cell or the bacterial cell? Give a reason for your answer.

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Visit Chapter 1 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Be prepared for some surprise answers as the Untamed Science crew hit the streets to ask people basic questions about science and biology.

Art in Motion Learn about the steps scientists use to solve problems. Change the variables, and watch what happens!

Art Review Review your understanding of the various steps of experimental processes.

InterActive Art Design your own experiment to test Redi's and Pasteur's spontaneous generation experiments.

1 CHAPTER Summary

1.1 What Is Science?

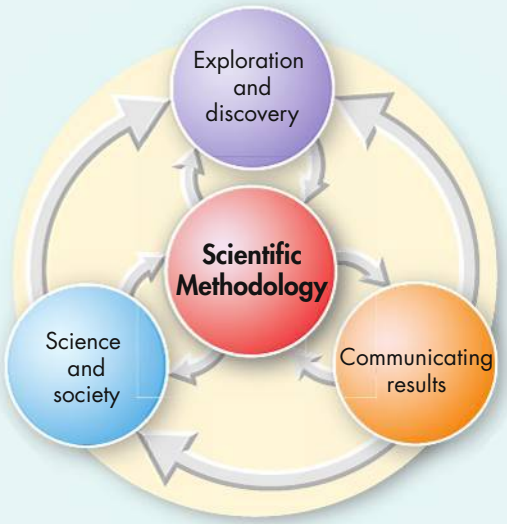
- The goals of science are to give natural explanations for natural events, to understand patterns, and to make predictions.
- Scientific methodology involves observing and asking questions, making inferences and forming hypotheses, doing controlled experiments, collecting and analyzing data, and drawing conclusions.

science (p. 4)
observation (p. 5)
hypothesis (p. 5)
controlled experiment (p. 6)
control group (p. 6)
data (p. 6)

1.2 Science in Context

- Curiosity, skepticism, open-mindedness, and creativity help scientists come up with new ideas.
- Publishing peer-reviewed papers in journals lets scientists share ideas and review each other's work.
- A scientific theory is a well-tested explanation that accounts for a lot of observations and hypotheses and that lets scientists make good predictions.
- Using science involves understanding its limitations and how it fits into society.

theory (p. 11)
bias (p. 12)



1.3 Studying Life

- Living things are made up of basic units called cells, are based on a universal genetic code, obtain and use materials and energy, grow and develop, reproduce, respond to their environment, maintain a stable internal environment, and change over time.
- Biology's big ideas are the cellular basis of life; information and heredity; matter and energy; growth, development, and reproduction; homeostasis; evolution; structure and function; unity and diversity of life; interdependence in nature; and science as a way of knowing.
- Biology is made up of many overlapping fields that use different tools to study life from the level of molecules to the whole planet.
- Most scientists use the metric system when collecting data and performing experiments.

biology (p. 13)
DNA (p. 14)
stimulus (p. 14)
homeostasis (p. 15)
metabolism (p. 15)
biosphere (p. 17)

1 CHECK Understanding

Assess the Big idea Science as a Way of Knowing

Write an answer to the question below.

Q: What role does science play in the study of life?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs long. To help you begin, read the **Hints** below each of the questions.

1. **Why are questions so important in the scientific method?**

   Hint Scientific investigation begins with observation.

2. **Predict some problems that might happen if some scientists used SI units to measure objects and other scientists used inches.**

   Hint Scientists need to replicate each other's experiments.

   Hint The metric system is based on multiples of 10.

3. **Suppose that a classmate says that a wooden chair is alive. He says that the wood comes from a tree and that trees are alive. Explain why your classmate is right or wrong.**

   Hint If something does not have all the characteristics of living things, it is not alive.

Foundations for Learning Wrap-Up

Use the Inspired Shape Tree that you made when you started the chapter as a tool to help you learn the characteristics of living things.

Activity 1 Remove a branch from your Inspired Shape Tree. Write the characteristic on a sheet of paper. Then, write a brief description of what would happen to a tree if the tree did not have that characteristic. Continue until you have removed all the branches from your Inspired Shape Tree.

Activity 2 Remove the branches from your Inspired Shape Tree. Turn each branch over and write one or two words related to the characteristic on the front side of the branch. Mix up the branches. Have a partner read the words on one of the branches. Try to explain the characteristic of that branch. If your partner thinks that you explained the characteristic clearly, he or she will give you the branch to attach to your tree trunk. Continue until all the branches are picked. Take turns.

1.1 What Is Science?

Understand Key Concepts

1. Which of the following statements about a controlled experiment is true?
   - **a.** All the variables must be kept the same.
   - **b.** Only one variable is tested at a time.
   - **c.** All hypotheses can be tested by setting up a controlled experiment.
   - **d.** Controlled experiments cannot be performed on living things.

Test-Taking Tip

Read All the Answer Choices If you are not sure of the answer to a question, read all of the choices before picking one. Then begin to cross out incorrect answers. Read question 1 again. If all the variables are kept the same, the experiment would not show any changes in the dependent variable. So, **a** is not correct. Choices **c** and **d** are not correct. Some experiments cannot be tested with controlled experiments, and some controlled experiments can be done on living things. Therefore, **b** is the correct answer.

2. An inference is
   - **a.** the same as an observation.
   - **b.** a logical interpretation of an observation.
   - **c.** a statement involving numbers.
   - **d.** a way to avoid bias.
3. To be useful in science, a hypothesis must be
   - **a.** measurable.
   - **b.** observable.
   - **c.** testable.
   - **d.** correct.

Think Critically

4. **Apply Concepts** Suggest an experiment that would test the hypothesis that one food is better than another at speeding an animal's growth.
5. **Explain** Explain why you cannot draw a conclusion about the effect of one variable in an investigation when other key variables are not controlled.

1.2 Science in Context

Understand Key Concepts

6. A skeptical attitude in science
   - **a.** prevents scientists from accepting new ideas.
   - **b.** makes the acceptance of new ideas more likely.
   - **c.** means a new idea will only be accepted if it is backed by evidence.
   - **d.** is unimportant.
7. The purpose of peer review in science is to ensure that
   - **a.** all scientific research is funded.
   - **b.** the results of experiments are correct.
   - **c.** all scientific results are published.
   - **d.** published results meet standards set by the scientific community.
8. A scientific theory is
   - **a.** the same as a hypothesis.
   - **b.** a well-tested explanation that unifies a broad range of observations.
   - **c.** the same as the conclusion of an experiment.
   - **d.** the first step in a controlled experiment.

Think Critically

9. **Infer** How would having a scientific attitude help you in everyday activities—in trying to learn a new skill, for example?
10. **Apply Concepts** If you were one of the reviewers of a paper submitted for publication, what criteria would you use to determine whether or not the paper should be published?

1.3 Studying Life

Understand Key Concepts

11. The process in which two cells from different parents unite to produce the first cell of a new organism is called
    - **a.** homeostasis.
    - **b.** development.
    - **c.** asexual reproduction.
    - **d.** sexual reproduction.

1 CHECK Understanding

Think Critically

12. Interpret Visuals Each of the following safety symbols might appear in a laboratory activity in this book. Describe what each symbol stands for. (**Hint:** Refer to Appendix B.)

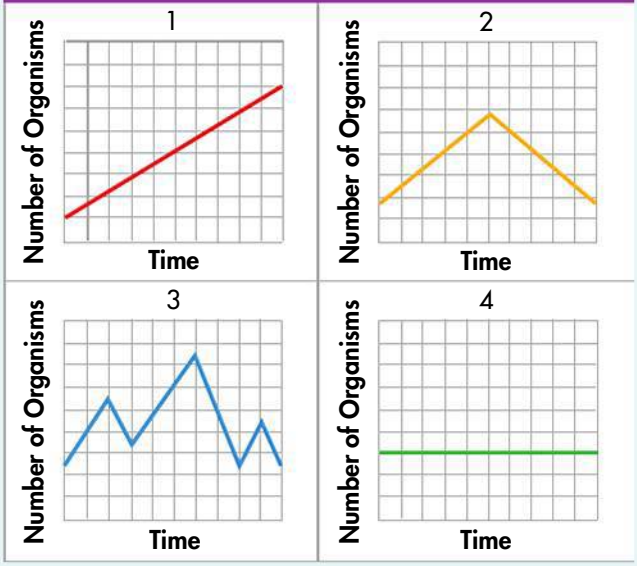
1 2 3 4

Connecting Concepts

Use Science Graphs

The following graphs show the size of four different populations over a period of time. Use the graphs to answer questions 13–15.

Changes in Four Populations



13. Analyze Data Write a sentence summarizing what each graph shows.

14. Interpret Graphs What information is missing from the graphs? (**Hint** Look at the *x* and *y* axes.)

15. Compare and Contrast Graphs of completely different events can look alike. Select one of the graphs and explain how the shape of the graph could apply to a different set of events.

solve the CHAPTER MYSTERY

HEIGHT BY PRESCRIPTION

Although scientific studies have not proved that HGH makes adults much taller, studies suggest that extra HGH may help some short kids grow taller sooner. David's doctor prescribed HGH so that David and his parents would not complain that HGH was not given as an option.

This situation is new. HGH used to be available only from cadavers, or dead bodies, and it was given only to people who had severe medical problems. Then, genetic engineering made it possible to make a lot of HGH—safe medicine for sick people.

Soon drug companies to began trying to sell HGH to parents of healthy, short kids.

As David's case shows, science can change lives, but new scientific knowledge may raise more questions than they answer. Just because science makes something possible, does that mean it's right to do it? This question is difficult to answer. When thinking about how science should be applied, we must consider both its limitations and its context in society.

1. Relate Cause and Effect Search the Internet for the latest data on the use of HGH by healthy children.

2. Predict HGH was among the first products to come out of genetic engineering. Many more will follow. As products become available that could change other inherited traits, what challenges will society face?

Untamed Science **Never Stop Exploring Your World.** Finding the solution to the HGH mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

Standardized Test Prep

Multiple Choice

1. To ensure that a scientific work is free of bias and meets standards set by the scientific community, a research group's work is peer reviewed by
A other scientists.
B the general public.
C the researchers' friends.
D lawmakers.

2. The term for the chemical reactions in which organisms build up or break down materials is
A biotechnology.
B genetics.
C metabolism.
D genomics.

3. Which of the following is NOT an attitude that scientists need?
A bias
B skepticism
C creativity
D open-mindedness

4. A bird-watcher sees an unusual bird at a feeder. He takes careful notes on the bird's color, shape, and other physical features and then goes to a reference book to see if he can identify the species. What part of scientific thinking is most apparent in this situation?
A observation
B inference
C hypothesis formation
D controlled experimentation

5. Unlike sexual reproduction, asexual reproduction involves
A two cells.
B two parents.
C one parent.
D one nonliving thing.

6. One meter is equal to
A 1000 millimeters.
B 1 millimeter.
C 10 kilometers.
D 1 milliliter.

Questions 7–8

Once a month, a pet owner recorded the mass of her puppy in a table. When the puppy was 3 months old, she started to feed it a "special puppy food" she saw advertised on TV.

Change in a Puppy's Mass Over Time

Age (months)	Mass at Start of Month (kg)	Change in Mass per Month (kg)
2	5	–
3	8	+3
4	13	+5

7. According to the table, which statement is true?
A The puppy's mass increased at the same rate for each month shown.
B The puppy's mass was less than 5 kg at the start of the new diet.
C The puppy gained 5 kg between age 3 and 4 months.
D The puppy had gained 13 kg as a result of the new diet.

8. All of the following statements about the pet owner's study are true EXCEPT
A The owner used the metric system.
B The owner recorded data.
C The owner could graph the data.
D The owner conducted a controlled experiment.

Open-Ended Response

9. Explain how a controlled experiment works.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9
See Lesson	1.2	1.3	1.2	1.1	1.3	1.3	1.1	1.1	1.1

2 The Chemistry of Life

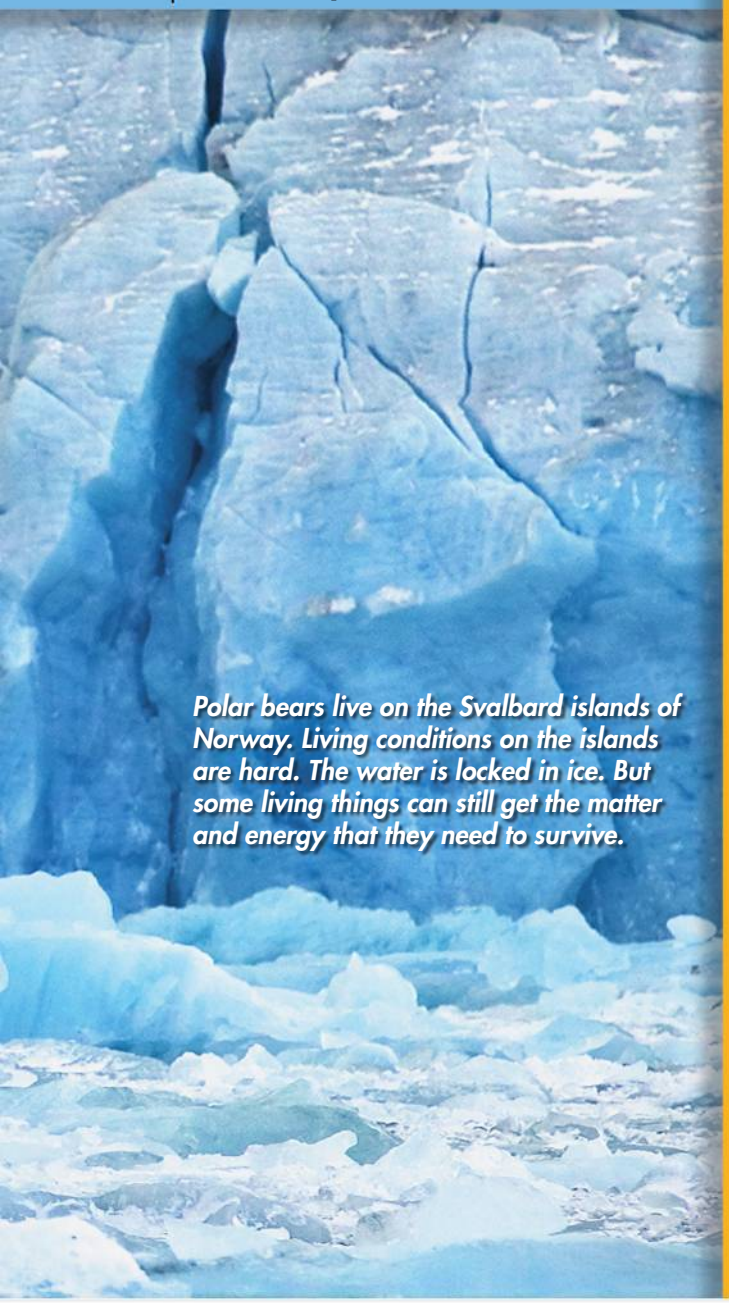
Big idea

Matter and Energy

Q: What are the basic chemical principles that affect living things?

BIOLOGY.com Search Chapter 2 GO • Flash Cards

INSIDE:



Polar bears live on the Svalbard islands of Norway. Living conditions on the islands are hard. The water is locked in ice. But some living things can still get the matter and energy that they need to survive.

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

THE GHOSTLY FISH

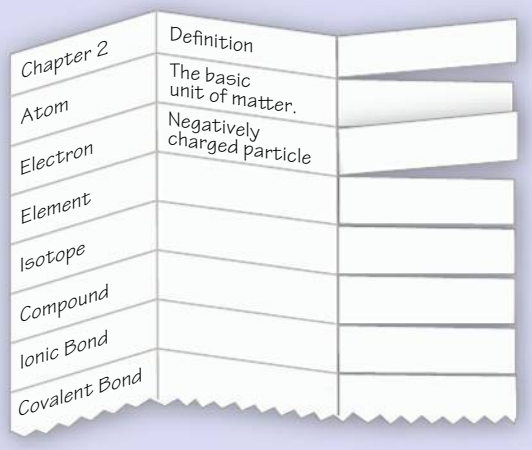
Most fish have red blood, just like other vertebrates. Red blood cells carry oxygen, a gas needed for life. The cell's red color comes from an oxygen-binding protein called hemoglobin (HEE muh gloh bin).

But some fish don't have red blood cells. Their blood is clear. Because they live in cold antarctic waters and look ghostly, they are called "ice fish." How do ice fish live without red blood cells?

Read for Mystery Clues As you read this chapter, look for clues to help you explain the ice fish's clear blood. Think about the chemistry that might be involved. Then, solve the mystery.

FOUNDATIONS for Learning

Vocabulary words are important for learning the key ideas of this chapter. Before you read this chapter, make a vocabulary quiz sheet. Fold a sheet of paper into three equal parts lengthwise. As you read the chapter, write the vocabulary words in the first column. Write the definition for each word in the second column next to the word. Then, cut the third column to make tabs. The tabs will cover up the definitions. At the end of the chapter are two activities that use the vocabulary quiz sheet to answer the question: What are the basic chemical principles that affect living things?



2.1 The Nature of Matter

Key Questions

- ***What three particles make up atoms?***
- ***How are all of the isotopes of an element similar?***
- ***How do compounds differ from the elements in them?***
- ***What are the main kinds of chemical bonds?***

BUILD Understanding

Previewing Visuals Before you read the chapter, study the carbon atom figure below. Learn where in an atom you can find protons, neutrons, and electrons.

In Your Workbook Go to your workbook for a way to preview visuals.

Atoms

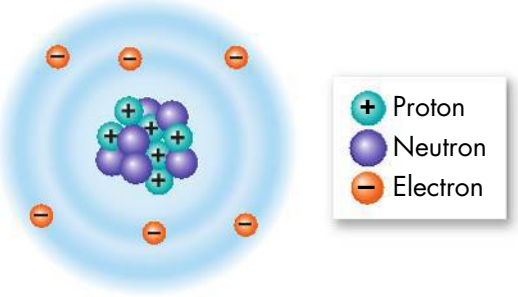
Nearly 2500 years ago, the Greek philosopher Democritus asked a simple question: If you break a stick of chalk in half, are both parts still chalk? The answer, of course, is yes. What happens if you break it in half again and again? Can you keep breaking it without changing it into something else? Democritus thought that there had to be a limit, and he was right. He called the smallest piece the atom. The **atom** is the basic unit of matter. The study of chemistry begins with atoms.

Atoms are very small. Placed side by side, 100 million atoms would make a row only about as wide as your little finger! Although they are small, atoms are made up of even smaller particles called protons, neutrons, and electrons.

Protons and Neutrons Protons and neutrons have about the same mass. However, protons are positively charged particles (+) and neutrons carry no charge at all. Strong forces hold protons and neutrons together to form the nucleus. The **nucleus** is the center of the atom.

Electrons An **electron** is a negatively charged particle (–). An electron has only 1/1840 the mass of a proton. Electrons are always moving around the nucleus. They are attracted to the positively charged nucleus. But electrons stay outside the nucleus because of the energy of their motion. Atoms have equal numbers of electrons and protons. So, the positive and negative charges balance and atoms have no charge.

Key Question What three particles make up atoms?
Protons, neutrons, and electrons are the particles that make up atoms.



A Carbon Atom A carbon atom has 6 protons and 6 electrons, in addition to the neutrons in its nucleus. Like all atoms, it has no charge, since the number of protons and electrons is equal.

Elements and Isotopes

An **element** is a pure substance that is made up of only one kind of atom. Each element has a one- or two-letter symbol. For example, the symbol for carbon is C, and the symbol for sodium is Na. The number of protons in the atom of an element is the element's atomic number. Carbon's atomic number is 6 because carbon atoms have 6 protons. Carbon atoms also have 6 electrons.

Isotopes Atoms of an element may have different numbers of neutrons. For example, all atoms of carbon have 6 protons, but each atom may have 6, 7, or 8 neutrons. Atoms of the same element that have different numbers of neutrons are **isotopes** (EYE suh tohps). The total number of protons and neutrons in an atom is the atom's mass number. Isotopes are named using their mass numbers. A carbon atom with 6 neutrons has a mass number of 12 and is called carbon-12. The table below shows the isotopes of carbon.

Radioactive Isotopes Some isotopes are radioactive, which means that the nucleus of the atom breaks down at a constant rate over time. When these isotopes break down, they give off energy or particles called radiation. Radiation can be dangerous, but radioactive isotopes have important uses.

Radioactive isotopes can help determine the ages of rocks and fossils. Radiation can help find and treat cancer and kill bacteria. Radioactive isotopes can also serve as labels or "tracers" to follow how substances move in organisms.

Key Question How are all of the isotopes of an element similar?

Isotopes of an element all have the same number of protons.

Isotopes of Carbon

Isotope	Number of Protons	Number of Electrons	Number of Neutrons
Carbon–12 (nonradioactive)	6	6	6
Carbon–13 (nonradioactive)	6	6	7
Carbon–14 (radioactive)	6	6	8

Carbon Isotopes Isotopes of carbon have the same number of protons but different numbers of neutrons. Isotopes are named by their mass number, which is the total number of protons and neutrons. So, an isotope that has 6 protons and 6 neutrons is called carbon-12.

BUILD Vocabulary

atom
the basic unit of matter

nucleus
the center of an atom, which contains the protons and neutrons

electron
a negatively charged particle; located in the space surrounding the nucleus

element
a pure substance that consists entirely of one type of atom

isotope
one of several forms of a single element, each of which contains the same number of protons but different numbers of neutrons

PREFIXES

The prefix *iso-* means "the same." Isotopes are atoms that have the same number of protons but different numbers of neutrons.

BUILD Vocabulary

compound
a substance formed by the chemical combination of two or more elements in definite proportions

ionic bond
a chemical bond formed when one or more electrons are transferred from one atom to another

covalent bond
a type of bond between atoms in which the electrons are shared

molecule
the smallest unit of most compounds that displays all the properties of that compound

PREFIXES

The prefixes *com-* and *co-* mean "together." A compound is made up of elements joined together, and a covalent bond contains atoms that share electrons together.

Chemical Compounds

Most elements are not found as single atoms. Instead, they are joined with other elements in compounds. A **compound** is a substance formed by the chemical combination of two or more elements in definite amounts. The number of each element in a compound can be shown by chemical formulas. For example, water has 2 atoms of hydrogen and 1 atom of oxygen. So, the chemical formula for water is H_2O.

The physical and chemical properties of a compound are different from the properties of the elements that make up the compound. For example, hydrogen and oxygen are gases at room temperature. But they can combine explosively to form liquid water.

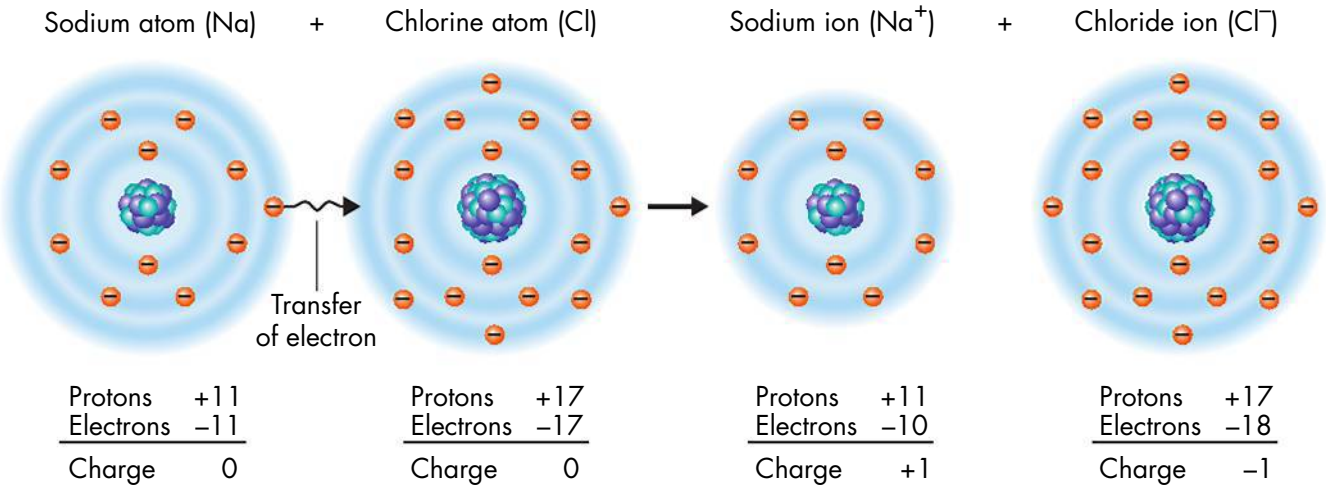
Key Question How do compounds differ from the elements in them?

Compounds have chemical and physical properties that are different from the properties of the elements in them.

Chemical Bonds

The atoms in compounds are held together by chemical bonds. The two main kinds of chemical bonds are ionic and covalent bonds.

Ionic Bonds An **ionic bond** is formed when one or more electrons are moved, or transferred, from one atom to another. An atom that loses electrons becomes positively charged. An atom that gains electrons has a negative charge. These positively and negatively charged atoms are known as ions. Oppositely charged ions are attracted to each other.

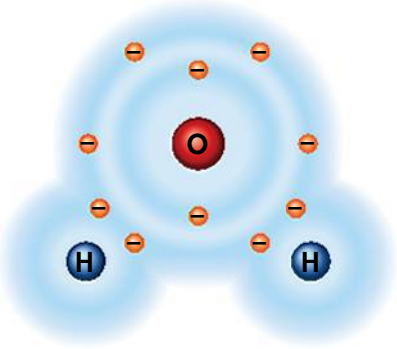


Ionic Bonding Table salt is made up of sodium ions and chloride ions. A sodium ion (Na^+) forms when a sodium atom loses 1 electron. A chloride ion (Cl^-) forms when a chlorine atom gains 1 electron. These oppositely charged ions attract each other and form an ionic bond.

Covalent Bonds Sometimes electrons are shared by atoms instead of being moved from one atom to another. What does it mean to share electrons? It means that the electrons travel around the nuclei of both atoms, forming a **covalent bond.** There are different types of covalent bonds. When atoms share 2 electrons, the bond is a single covalent bond. If atoms share 4 electrons, then the bond is a double bond. Atoms can also share 6 electrons and form a triple bond.

The structure that results when atoms are joined together by covalent bonds is called a molecule. The **molecule** is the smallest unit of most compounds. The bonds in a water molecule are covalent bonds. Each hydrogen atom in a water molecule is joined to the oxygen atom by a single covalent bond. Oxygen can also form double bonds. For example, the oxygen molecules that you breathe are 2 oxygen atoms joined by a double bond.

Key Question What are the main kinds of chemical bonds?
The main kinds of chemical bonds are ionic bonds and covalent bonds.



Water molecule (H_2O)

Covalent Bonding In a water molecule, each hydrogen atom shares 2 electrons with the oxygen atom. So, each hydrogen atom is joined to the oxygen atom by a covalent bond.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A(n) _____ is the basic unit of matter.
2. Sodium and chlorine form a(n) _____ when an electron moves from the sodium atom to the chlorine atom.
3. _____ are negatively charged and move around the nucleus of an atom.

Critical Thinking

4. **Infer** An atom of calcium has 20 protons. How many electrons does it have?
5. **Compare and Contrast** Compare carbon-12 and carbon-14 atoms. How are they the same, and how are they different?
6. **Apply Concepts** A potassium atom can easily lose 1 electron. What kind of bond will potassium form with chlorine?
7. **Write to Learn** Answer the first clue of the mystery. Write two or three sentences that include the words *atom* and *electron*.

Fish do not break water molecules apart to get oxygen. Instead, they use oxygen gas that is dissolved in the water. How are the atoms in an oxygen molecule joined together? (Hint: See above.)

BIOLOGY.com Search Lesson 2.1 GO • Lesson Assessment

Model an Ionic Compound

Ionic bonds are formed when electrons transfer from one atom to another. Sodium chloride, or table salt, is an ionic compound. To form table salt, sodium "gives" an electron to chlorine. The sodium atom then has more protons than electrons. It is an ion with a positive charge. The chlorine atom has more electrons than protons. It is an ion with a negative charge. Sodium and chloride ions form an orderly structure called a crystal.

In Lesson 2.1, you learned about ionic bonds and how these bonds form in table salt. In this activity, you will build a model of table salt.

1. Find a partner. One of you will make a model of a sodium atom, and the other will make a model of a chlorine atom.
2. Use the table below to find the correct number of electrons in your atom. Use popcorn kernels to represent the electrons in your atom.
3. Write the number of protons in your atom in the center of an index card and draw a circle around this number. This circle is the nucleus of your atom.
4. Arrange the correct number of electrons (popcorn kernels) on the index card around the nucleus.
5. Move your atom close to your partner's atom. Use the two atom models to form the ionic compound sodium chloride—table salt. (Form the ionic compound by moving an electron from one atom to the other.)
6. In table salt, the closely packed sodium and chloride ions form an orderly structure called a crystal. Using your compound models, work in a small group to model a sodium chloride crystal.

Analyze and Conclude

1. Relate Cause and Effect Describe how the popcorn kernels (electrons) moved as you formed the ionic bond. What electrical charges resulted from the movement?

2. Use Models How did you arrange the ions in the crystal model? Why did you choose this arrangement?

In Your Workbook Go to your workbook for more help with this activity.

Isotope	Number of Protons	Number of Electrons	Number of Neutrons
Sodium-23	11	11	12
Chrorline-35	17	17	18

2.2 Properties of Water

The Water Molecule

Water is a compound found over most of Earth's surface. In fact, just finding liquid water on a planet tells scientists that there could be life on that planet. What properties of water make it so important?

A Polar Molecule Like other molecules, water (H_2O) is neutral. The positive charges on its 10 protons balance out the negative charges on its 10 electrons. But an oxygen atom has 8 protons whereas a hydrogen atom has only 1. So, the electrons in a water molecule are pulled more toward the oxygen atom. They spend more time near the oxygen atom than near the hydrogen atoms. The oxygen atom is found on one end of the water molecule and the hydrogen atoms are on the other. As a result, the oxygen end of the molecule has a slight negative charge and the hydrogen end has a slight positive charge.

A molecule in which the charges are unevenly spread out is said to be "polar." The charges on a polar molecule are written in parentheses, (–) or (+), to show that they are weaker than the charges on ions such as Na^+ and Cl^-.

Hydrogen Bonds Because of their partial positive and negative charges, polar molecules such as water can attract each other. The pull between a partially positive hydrogen atom on one molecule and a partially negative oxygen atom on another is known as a hydrogen bond. Hydrogen bonds form between the hydrogen atoms and oxygen atoms of different water molecules. Because water is a polar molecule, it can form many hydrogen bonds. Hydrogen bonds are not as strong as covalent or ionic bonds. But the hydrogen bonds do give water some special properties.

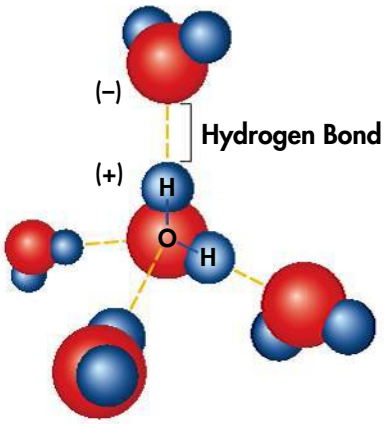
Key Questions

- ***How does the structure of water lead to its special properties?***
- ***How does water's polarity affect its properties as a solvent?***
- ***Why is it important for cells to buffer solutions against rapid changes in pH?***

BUILD Understanding

Venn Diagram As you read, draw a Venn diagram to compare solutions and suspensions. The diagram should show similarities and differences between the two.

In Your Workbook Go to your workbook to learn more about making a Venn diagram. Complete the Venn diagram for Lesson 2.2.



Hydrogen Bonding The molecules shown are water molecules. The red atoms are oxygen, and the blue atoms are hydrogen. The dashed lines show the hydrogen bonds that can form between water molecules.

Adhesion Adhesion between the molecules in the glass and the molecules in the water causes water to stick to the sides of this glass tube. The water climbs up the sides, and the water dips down in the middle. This curved water surface is called a meniscus.

BUILD Vocabulary

cohesion
the attraction between molecules of the same substance

adhesion
the force of attraction between different kinds of molecules

solution
a type of mixture in which all the components are evenly distributed

suspension
a mixture of water and nondissolved material

acid
a compound that releases hydrogen ions (H^+) in solution; a solution with a pH of less than 7

base
a compound that releases hydroxide ions (OH^-) in solution; a solution with a pH of more than 7

buffer
a compound that prevents sharp, sudden changes in pH

PREFIXES

The prefix *co-* means "together." Cohesion pulls molecules of the same substance together.

▶ ***Cohesion*** Because a water molecule can have as many as four hydrogen bonds at the same time, water is very cohesive. **Cohesion** (koh HEE zhun) is an attraction between molecules of the same substance. Cohesion pulls water molecules together. It causes surface tension, which enables some insects to walk on water's surface.

▶ ***Adhesion*** On the other hand, **adhesion** (ad HEE zhun) is an attraction between molecules of different substances. Adhesion between water and glass makes the surface of water in a tube curve upward along the sides of the tube. Adhesion also makes water rise in a narrow tube. This effect is called capillary action. Capillary action helps draw water out of the roots of a plant and up into its stems and leaves.

▶ ***Heat Capacity*** Another special property of water is its high heat capacity. Heat capacity is the amount of heat energy needed to increase a substance's temperature. In order for the temperature of water to rise, the molecules must move faster. The hydrogen bonds make it hard for water molecules to move faster. This property allows large bodies of water like oceans and lakes to absorb large amounts of energy without large changes in temperature.

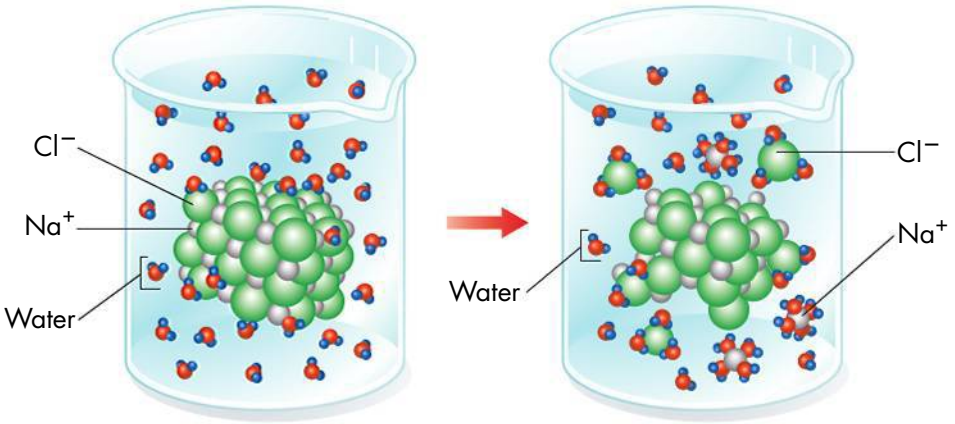
Key Question How does the structure of water lead to its special properties?

Water is polar, so it can form hydrogen bonds. These bonds give water special properties, including cohesion, adhesion, and a high heat capacity.

Solutions and Suspensions

Water is often found as part of a mixture. A mixture is made up of elements or compounds that are combined but not bonded together. Living things are partly made up of water mixtures. Two kinds of mixtures that are made with water are solutions and suspensions.

Solutions If you put table salt in water, the ions on the salt's surface will be pulled toward the polar water molecules. Ions break away from the salt and are surrounded by water molecules. The ions spread out in the water to make a solution. A **solution** is a mixture in which the molecules of the mixed substances are evenly spread out. Solutions are made up of one or more solutes in a solvent. A solute is what is dissolved. A solvent is what does the dissolving. So, in a saltwater solution, salt is the solute and water is the solvent. Because water is polar, it can dissolve ionic compounds and other polar molecules.



A Salt Solution An ionic compound, such as salt, dissolves in water. The water molecules surround the ions and pull them apart.

Suspensions Some things do not dissolve in water. But they may break into pieces so small that they do not settle out. Mixtures of water and nondissolved material that do not settle out are **suspensions.** Some important fluids in living things are both solutions and suspensions. Blood is mostly water. The water in the blood contains many dissolved compounds. But blood also has cells and other particles in suspension.

Key Question How does water's polarity affect its properties as a solvent?

Because water is polar, it can dissolve ionic compounds and other polar molecules.

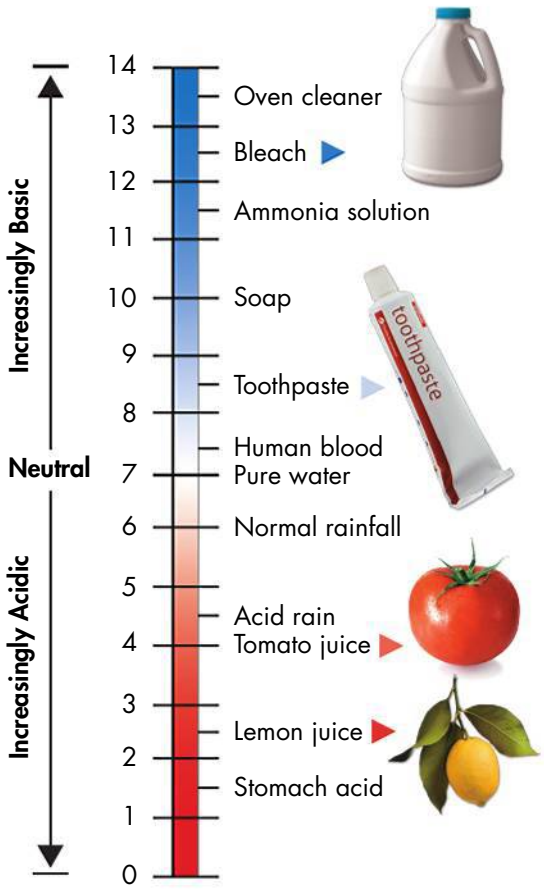
Acids, Bases, and pH

Water molecules sometimes break apart to form ions. This reaction can be shown by a chemical equation. The double arrows show that the reaction can happen in either direction.

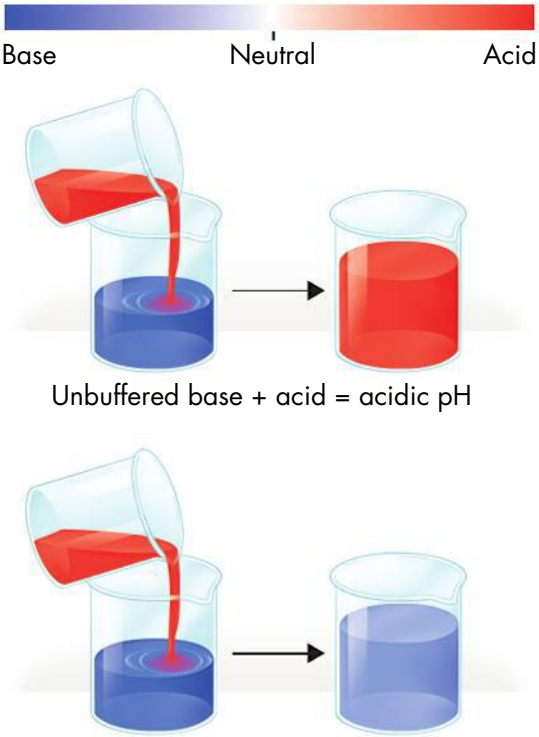
$$H_2O \rightleftharpoons H^+ + OH^-$$

water ⇌ hydrogen ion + hydroxide ion

The pH Scale Chemists use a measurement system called the pH scale to show the concentration of H^+ ions in solution. The pH scale ranges from 0 to 14. At a pH of 7, the concentration of H^+ ions and OH^- ions is equal. Pure water has a pH of 7. Solutions that have a pH below 7 are acidic. They have more H^+ ions than OH^- ions. The lower the pH is, the greater the acidity is. Solutions that have a pH above 7 are basic. They have more OH^- ions than H^+ ions. The higher the pH is, the more basic the solution is.



The pH Scale The concentration of H^+ ions determines whether a solution is acidic or basic.



Buffers Adding an acid to a solution without a buffer causes the pH of the solution to drop. But if the solution has a buffer, adding an acid will cause only a small change in pH.

Acids An **acid** is any compound that releases H^+ ions in solution. Acidic solutions have pH values below 7. Strong acids tend to have pH values that range from 1 to 3. The hydrochloric acid (HCl) made by the stomach to digest food is a strong acid.

Bases A compound that releases hydroxide (OH^-) ions in solution is called a **base.** Basic solutions have pH values above 7. Strong bases, such as the lye (NaOH) used in soapmaking, tend to have pH values ranging from 11 to 14.

Buffers The pH in most cells in the human body must stay between 6.5 and 7.5. If the pH is lower or higher, it will affect the chemical reactions that take place in cells. So, keeping pH from changing is an important part of homeostasis (hoh mee oh STAY sis). Homeostasis is the process of keeping a stable internal environment inside living things. One way to control pH is with buffers. **Buffers** are weak acids or bases that can react with strong acids or bases to stop sharp, sudden changes in pH. Blood has a normal pH of 7.4. Sudden changes in blood pH are usually stopped by buffers. Buffers play an important role in keeping homeostasis in living things.

Key Question Why is it important for cells to buffer solutions against rapid changes in pH?
Buffers play an important role in keeping homeostasis in living things.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Cells do not dissolve in blood, but they form a _____ because they do not settle out of the blood either.
2. _____ stop sudden changes in pH.

Critical Thinking

3. **Explain** What property of water molecules allows them to form hydrogen bonds?
4. **Compare and Contrast** What is the difference between a solution and a suspension?
5. **Infer** During exercise many chemical changes happen in the body, including a drop in blood pH, which can be very serious. How is the body able to deal with such changes?
6. **Write to Learn** Answer the second clue of the mystery.

MYSTERY CLUE

The ability of a gas to dissolve increases as temperatures decrease. How might the temperature of antarctic water affect the amount of dissolved oxygen available for ice fish? (Hint: See p. 34.)

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2.3 Carbon Compounds

The Chemistry of Carbon

The chemistry of carbon is very important for living things. In fact, a whole branch of chemistry is set aside just to study carbon compounds. Why is carbon so interesting? There are two reasons. First, carbon atoms have four electrons available for bonding. These four electrons allow carbon atoms to form as many as four strong covalent bonds. Carbon can bond with many elements, including hydrogen, oxygen, phosphorus, sulfur, and nitrogen, to form the molecules of living things. Organisms are made up of molecules that consist of carbon and these other elements.

The second reason carbon compounds are so interesting is that carbon atoms can bond with each other. Bonding between carbon atoms gives carbon the ability to form chains that can be unlimited in length. These carbon-carbon bonds can be single, double, or triple covalent bonds. Chains of carbon atoms can even close up on themselves to form rings. Carbon can form millions of different large and complex structures. No other element comes close to matching carbon's ability to make so many different compounds.

Key Question What elements does carbon bond with to make up life's molecules? **Carbon bonds with hydrogen, oxygen, phosphorus, sulfur, and nitrogen to form life's molecules.**

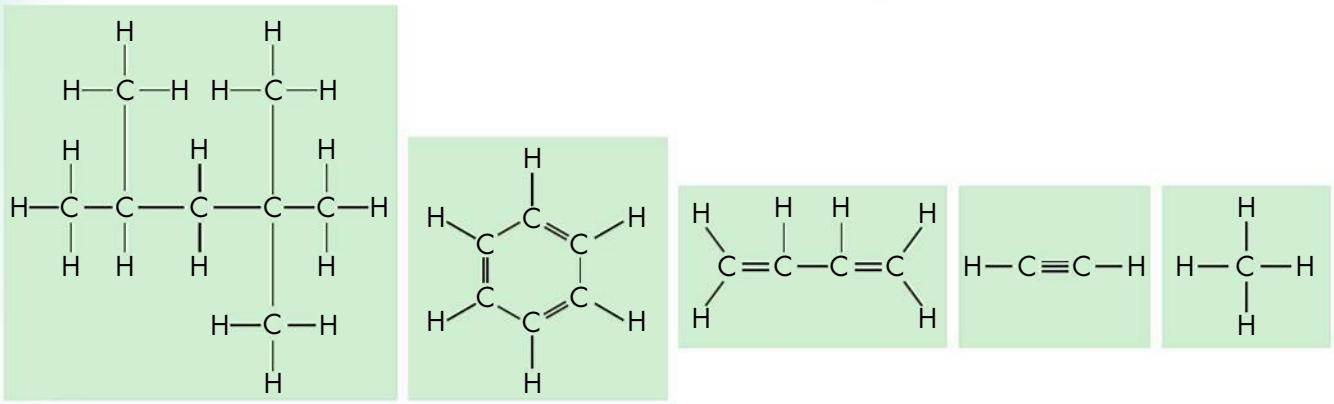
Key Questions

- ***What elements does carbon bond with to make up the molecules of living things?***
- ***What are the functions of each of the four groups of macromolecules?***

BUILD Understanding

Compare/Contrast Table As you read, make a table that compares and contrasts the four groups of macromolecules.

In Your Workbook Go to your workbook to learn more about making a compare/contrast table. Fill out the compare/contrast table for Lesson 2.3.



Isooctane | Benzene | Butadiene | Acetylene | Methane

Carbon Structures Carbon can form single, double, or triple bonds with other carbon atoms. Each line between atoms in a molecular structure is one covalent bond. Carbon atoms can form straight chains, rings, or branched chains.

BUILD Vocabulary

carbohydrate
a compound made up of carbon, hydrogen, and oxygen atoms; a type of nutrient that is the main source of energy for the body

lipid
a macromolecule made mostly from carbon and hydrogen atoms; includes fats, oils, and waxes

WORD ORIGINS

Carbohydrate is a combination of the prefix *carbo-*, which means "carbon," and the word *hydrate*, which means "water."

Macromolecules

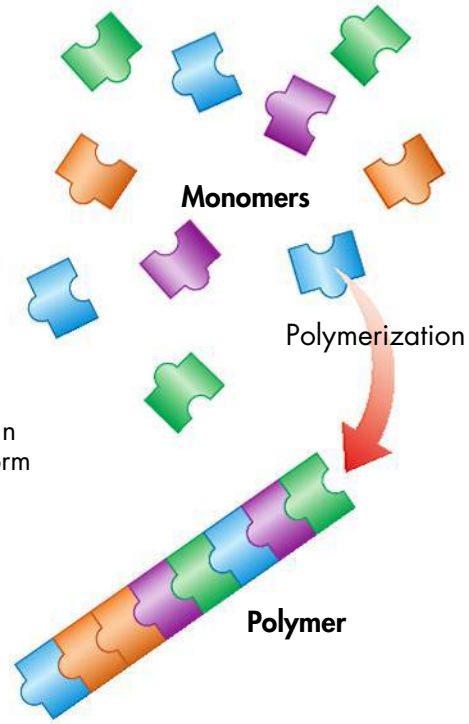
Many of the carbon compounds in living cells are so large that they are known as macromolecules or "giant molecules." Macromolecules are made from thousands or even hundreds of thousands of smaller molecules. The smaller units, or monomers, join together to form polymers (PAHL uh murz). The monomers in a polymer may be the same, like links in a chain. Or, the monomers may be different, like different colored beads in a necklace.

Scientists sort the macromolecules found in living things into groups based on their chemical makeup. The four major groups of macromolecules found in living things are carbohydrates, lipids, nucleic acids, and proteins.

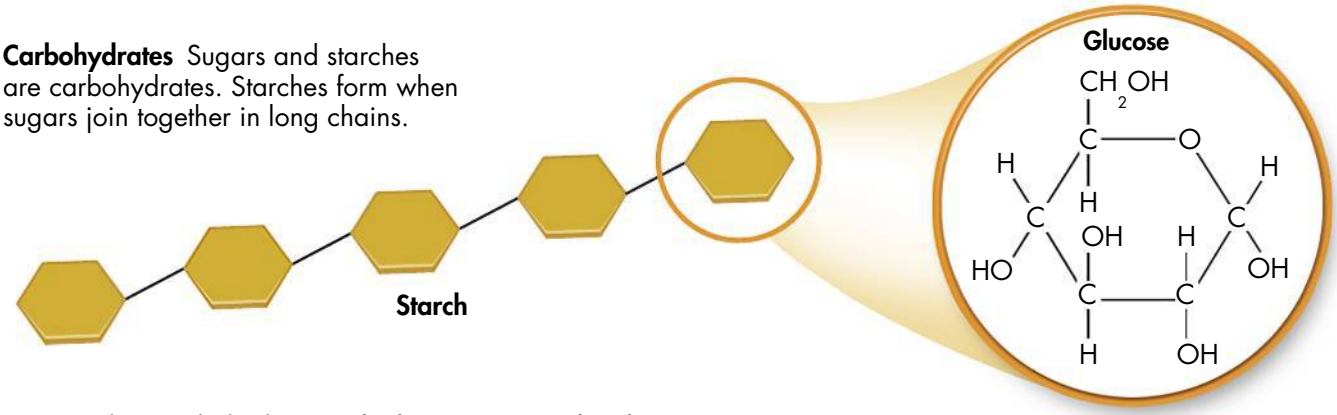
Carbohydrates Compounds made up of carbon, hydrogen, and oxygen atoms are called **carbohydrates.** There are usually twice as many hydrogen atoms as carbon or oxygen atoms in these molecules. Living things use carbohydrates as their main source of energy. Carbohydrates give plants, some animals, and other organisms structure. Sugars are carbohydrates. The breakdown of sugars, such as glucose, supplies energy for cell activities. Many living things store extra sugar as a carbohydrate called starch.

▶ ***Simple Sugars*** Single sugar molecules are called both monosaccharides (mahn oh SAK uh rydz) and simple sugars. Besides glucose, simple sugars include galactose, which is found in milk, and fructose, which is found in many fruits. Table sugar, sucrose, is made up of glucose and fructose. Since sucrose is made of two sugars it is called a disaccharide.

Key Question What are the functions of carbohydrates?
Carbohydrates provide energy and structural support for living things.



Polymerization Most macromolecules are formed by a process known as polymerization (pah lih mur ih ZAY shun). In this process, monomers join together to form polymers. Polymers can get very large.



Carbohydrates Sugars and starches are carbohydrates. Starches form when sugars join together in long chains.

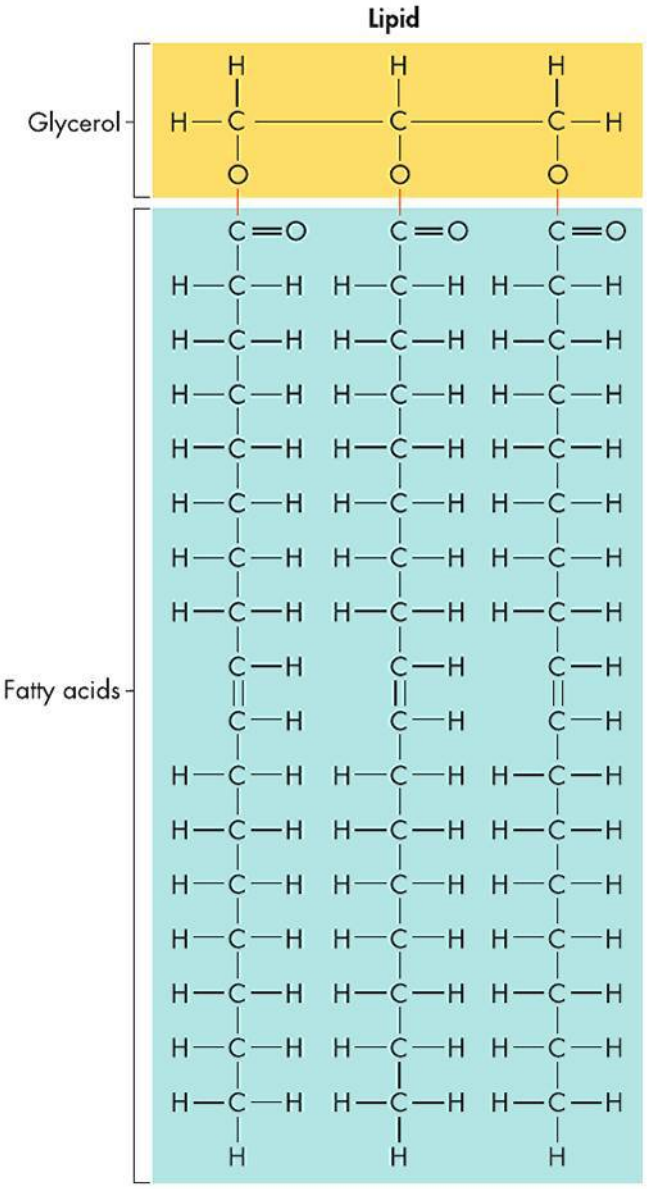
▶ ***Complex Carbohydrates*** The large macromolecules formed when simple sugars join together are called complex carbohydrates. Many animals store extra sugar in a complex carbohydrate called glycogen. When the amount of glucose in your blood runs low, glycogen is broken down into glucose, which then goes into the blood. The glycogen stored in your muscles gives energy to muscles so that you can move.

Plants use a different complex carbohydrate, called starch, to store extra sugar. Plants also make another complex carbohydrate called cellulose. Cellulose gives plants their strength and rigidity. Cellulose is the major part of wood and paper, so you are looking at cellulose as you read these words!

Lipids Fats, oils, and waxes are common lipids. **Lipids** are macromolecules that generally do not dissolve in water and are made mostly of carbon and hydrogen atoms. Some lipids store energy. Others form biological membranes, and some produce waterproof coverings on cells and tissues.

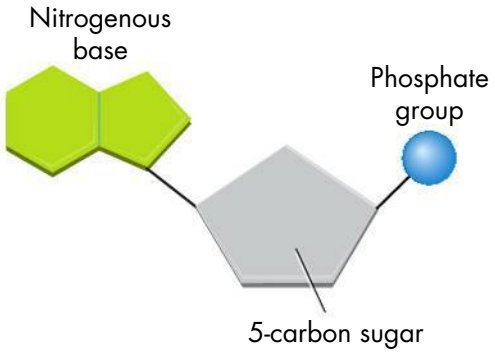
Many lipids are formed when a glycerol molecule joins with compounds called fatty acids. If each carbon atom in a lipid's fatty acids is joined to other carbon atoms by only single bonds, the lipid is called saturated. This means that the fatty acid has the most hydrogen atoms it can have. If there is at least one carbon-carbon double bond in a fatty acid, the fatty acid is called unsaturated. You have probably seen the terms *saturated* and *unsaturated* on food labels. Lipids that have unsaturated fatty acids are liquid at room temperature. Olive oil is one such lipid.

Key Question What are the functions of lipids?
Lipids are used to store energy and are parts of membranes and waterproof coverings.



Lipids Lipids are made up of a glycerol molecule and fatty acids.

Nucleotides Each nucleotide is made up of a 5-carbon sugar, a phosphate group, and a nitrogenous base. Nucleic acids are made up of many nucleotides joined together.



BUILD Vocabulary

nucleic acid
a macromolecule containing hydrogen, oxygen, nitrogen, carbon, and phosphorus

protein
a macromolecule that contains carbon, hydrogen, oxygen, and nitrogen; needed by the body for growth and repair

amino acid
a compound with an amino group on one end and a carboxyl group on the other end

WORD ORIGINS

The root word *nucle-* refers to a nucleus, or center, of something. In *nucleic acid* the root word refers to the nucleus of a cell, not of an atom.

Nucleic Acids

Nucleic (noo KLEE ik) **acids** are macromolecules containing hydrogen, oxygen, nitrogen, carbon, and phosphorus. Nucleic acids are polymers. They are made up of monomers called nucleotides (NOO klee oh tydz). Nucleotides have three parts: a 5-carbon sugar, a phosphate group ($-PO_4$), and a nitrogenous base. Some nucleotides, including adenosine triphosphate (ATP), help in storing and transferring energy.

Single nucleotides can be linked by covalent bonds into long chains known as nucleic acids. Nucleic acids store and transmit genetic information. There are two kinds of nucleic acids: ribonucleic acid (RNA) and deoxyribonucleic acid (DNA). RNA contains the sugar ribose, and DNA contains the sugar deoxyribose.

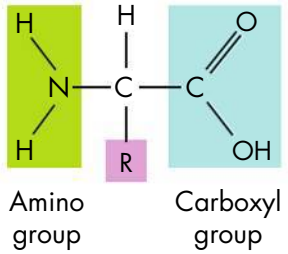
Key Question What are the functions of nucleic acids?
Nucleic acids store and transmit genetic information.

Proteins

Proteins are macromolecules that contain nitrogen as well as carbon, hydrogen, and oxygen. **Proteins** are polymers of molecules called amino acids. **Amino acids** are compounds with an amino group ($-NH_2$) on one end and a carboxyl group (–COOH) on the other end. Covalent bonds called peptide bonds link amino acids to form one or more polypeptides. A protein is a molecule made from one or more polypeptides. Some proteins control cell processes and the rate of reactions. Others form important parts in cells, while still others move substances into or out of cells or help to fight disease.

Amino Acids All amino acids have an amino group and a carboxyl group. The *R* in the structure shows where the side chain of the amino acid goes. Different side chains have different properties.

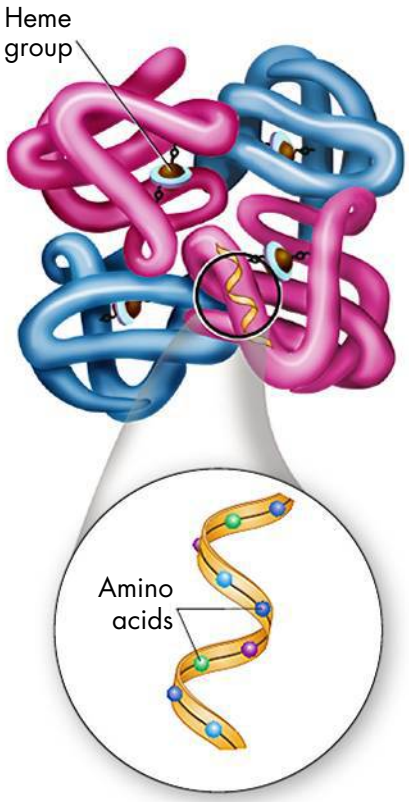
General Structure of Amino Acids



▶ ***Structure and Function*** More than 20 different amino acids are found in nature. All amino acids are the same in the regions where they may be joined together by covalent bonds. This uniformity allows any amino acid to be joined to any other amino acid. Each amino acid has a different side chain called an R-group. The side chains have different properties. Some chains are acidic and some are basic. Some are polar, some are nonpolar, and some even contain large ring structures. Because the side chains are so different, proteins are diverse macromolecules.

▶ ***Levels of Structure*** Amino acids are joined in long chains according to instructions coded in DNA. Scientists describe proteins as having four levels of structure. A protein's primary structure is the order of its amino acids. Its secondary structure is the folding of the polypeptide chain. The third level of structure is the three-dimensional arrangement of a chain. Proteins that have more than one chain have a fourth level of structure. The fourth level describes how the different chains are placed next to each other. Hemoglobin, a protein in red blood cells that helps move oxygen in blood, has four levels of structure. The shape of a protein is kept by many forces, including ionic, covalent, and hydrogen bonds. The heme groups in the protein bind oxygen and also give hemoglobin its red color.

Key Question What are the functions of proteins?
Some proteins control cell processes and the rate of reactions. Others form important parts in cells, while still others move substances into or out of cells or help to fight disease.



Protein Structure Hemoglobin is a protein made up of four polypeptide chains. Near the center of each polypeptide is an iron-containing heme group. An oxygen molecule is bound by each heme group.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Fats, oils, and waxes do not dissolve in water and are kinds of macromolecules called _____.
2. _____ store genetic information.
3. Compounds made up of carbon, hydrogen, and oxygen that are the main source of energy for the body are called _____.

Critical Thinking

4. **Relate Cause and Effect** Why can carbon form so many different structures?
5. **Explain** How do living things use lipids?
6. **Sequence** What are the four levels of organization in a protein?
7. **Write to Learn** Make a chart that shows the monomers that make up three of the four kinds of macromolecules.

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2.4 Chemical Reactions and Enzymes

Key Questions

- ***What happens to chemical bonds during chemical reactions?***
- ***How do energy changes affect whether a chemical reaction will happen?***
- ***What role do enzymes play in living things and what affects their function?***

BUILD Understanding

Concept Map As you read, make a concept map that shows the relationship among the vocabulary words in this lesson.

In Your Workbook Go to your workbook for help in completing the concept map for Lesson 2.4.

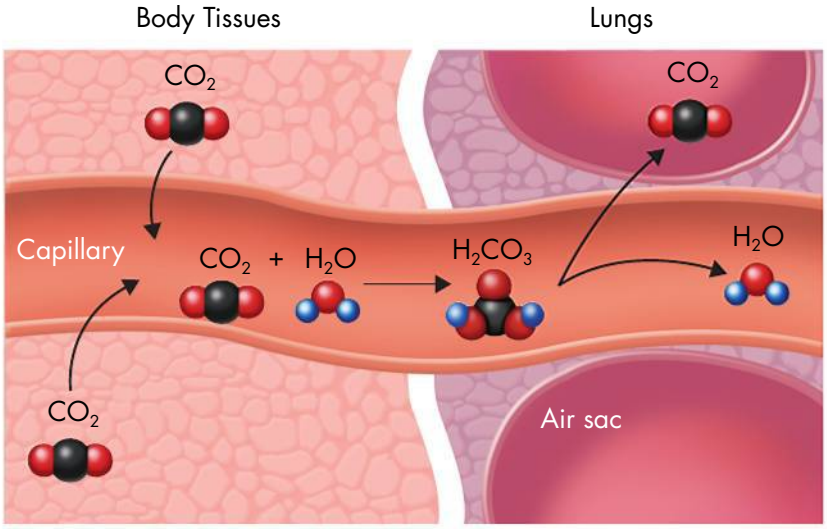
Chemical Reactions

Living things are made up of chemical compounds. But chemistry is not just what life is made of—chemistry is also what life does. Everything that happens in living things is based on chemical reactions. A **chemical reaction** is a process that changes one set of chemicals into another. Chemical reactions also involve changes in energy. Some reactions release energy, and some use energy. This is also true for chemical reactions that happen in living things.

Some chemical reactions happen slowly, such as the reaction of iron and oxygen to form rust. Other reactions happen quickly. The elements or compounds that go into a chemical reaction are reactants. The elements or compounds that come out of a chemical reaction are products. During chemical reactions, some chemical bonds are broken and other bonds are formed. An important reaction in your bloodstream removes carbon dioxide from the body. That reaction is shown below.

Key Question What happens to chemical bonds during chemical reactions?

During chemical reactions, some bonds are broken and other bonds are formed.



Reaction in the Bloodstream Carbon dioxide (CO_2) reacts with water (H_2O) to make carbonic acid (H_2CO_3). Your blood carries carbonic acid to your lungs. In your lungs, carbonic acid breaks apart to form water and carbon dioxide. You then breathe the carbon dioxide out.

Energy in Reactions

Energy is given off or taken in whenever chemical bonds are formed or broken. This means that chemical reactions involve changes in energy.

Energy Changes Energy changes are very important in determining whether a chemical reaction will happen. Chemical reactions that give off energy often happen on their own. Chemical reactions that take in energy will not happen without a source of energy. The burning of hydrogen gas gives off energy. Hydrogen reacts with oxygen to make water vapor.

$$2H_2 + O_2 \longrightarrow 2H_2O$$

If the hydrogen explodes, light and sound are given off in addition to the water vapor. The reverse reaction, in which water is changed into hydrogen and oxygen gas, requires so much energy that it doesn't happen by itself. In fact, the only way to reverse the reaction is to pass an electrical current through water to break the water down.

Energy Sources To stay alive, organisms need to carry out reactions that need added energy. Every living thing must have a source of energy to carry out these chemical reactions. Plants get that energy by trapping and storing the energy from sunlight in energy-rich compounds. Animals get their energy when they eat plants or other animals. Humans release energy needed to live when they break down the food they eat.

Activation Energy Chemical reactions that give off energy do not always happen on their own. If they did, the pages of this book might burst into flames! The cellulose in paper can burn and give off heat and light. However, paper burns only if you light it with a match, which gives enough energy to start the reaction. Chemists call the energy that is needed to get a reaction started **activation energy.** Energy is involved in all chemical reactions, whether the overall reaction gives off or takes in energy.

Key Question How do energy changes affect whether a chemical reaction will happen?
Chemical reactions that give off energy often happen on their own. Chemical reactions that take in energy will not happen without a source of energy.

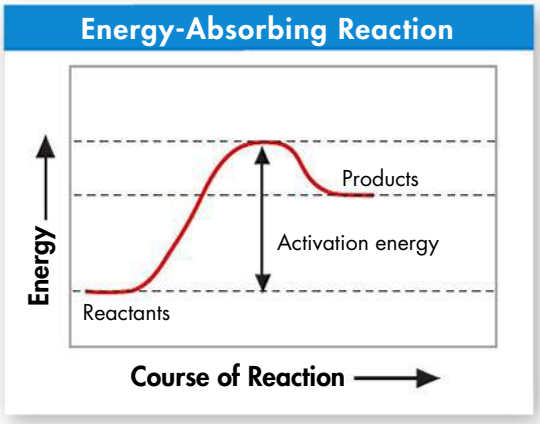
BUILD Vocabulary

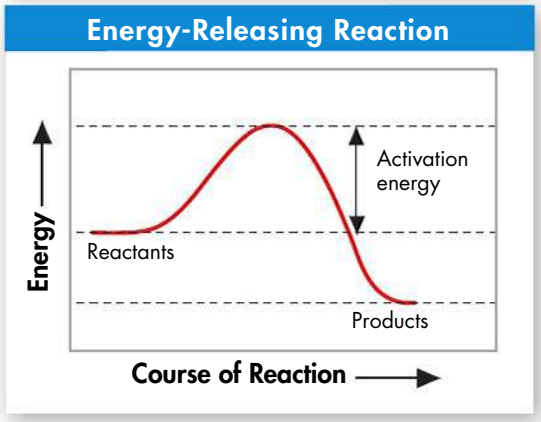
chemical reaction
the process that changes, or transforms, one set of chemicals into another set of chemicals

activation energy
the energy that is needed to get a reaction started

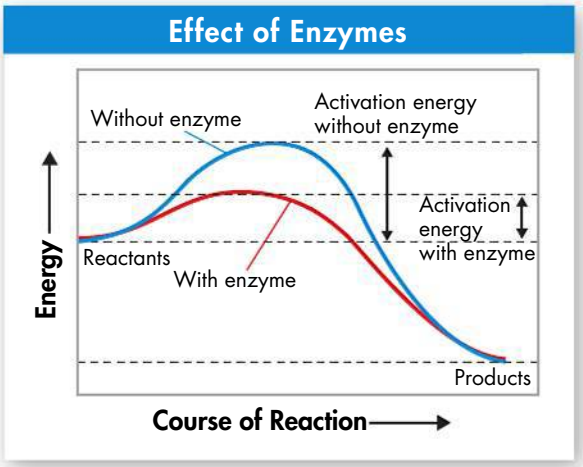
RELATED WORD FORMS

The verb *react* means "to act in response to something." The adjective *reactive* describes the tendency to react.





Activation Energy The high point of each graph shows the energy needed for the reaction to happen. The difference between this needed energy and the energy of the reactants is the activation energy.



Effect of Enzymes Adding an enzyme lowers the activation energy of reactions. The enzyme speeds up reactions.

Enzymes

Some chemical reactions that make life possible are too slow to make them practical for living tissue. These chemical reactions need the help of catalysts. A **catalyst** is a substance that speeds up the rate of a chemical reaction. Catalysts work by lowering a reaction's activation energy.

Nature's Catalysts Many reactions in living things need catalysts. **Enzymes** are proteins that act as catalysts in living things. Enzymes speed up chemical reactions that take place in cells. Each enzyme generally works on only one chemical reaction in the body. Like other catalysts, enzymes lower activation energies. This has a big effect on how quickly a reaction happens. An enzyme affects the speed of a reaction in your blood that joins carbon dioxide and water to make carbonic acid, as shown below.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

Left to itself, this reaction is very slow. It is so slow, in fact, that dangerous levels of carbon dioxide could build up in your body. But the enzyme carbonic anhydrase makes the reaction happen immediately so that carbon dioxide is removed quickly.

Enzymes and Substrates How do enzymes do their jobs? For a chemical reaction to take place, the reactants must hit each other with enough energy for existing bonds to break and for new bonds to form. If the reactants do not have enough energy, they will not react.

An enzyme has a site where reactants can be brought together to react. This site lowers the energy needed for a reaction. The reactants of enzyme-catalyzed reactions are known as substrates. The substrates bind to a site on the enzyme called the active site. At the active site, the enzyme changes a substrate slightly so that a specific chemical bond is weakened. This weakened bond allows a chemical reaction to happen quickly. The active site and the substrates fit together like puzzle pieces. The fit is so precise that the active site and substrates are often compared to a lock and key.

Controlling How Enzymes Work Enzymes have important roles in controlling chemical reactions, making materials that cells need, giving off energy, and sending information. Enzymes are catalysts for reactions, so they can be affected by many things. Temperature, pH, and other molecules can affect how enzymes work.

BUILD Vocabulary

catalyst
a substance that speeds up the rate of a chemical reaction

enzyme
a protein catalyst that speeds up the rate of specific biological reactions

MULTIPLE MEANINGS

When the word *catalyst* is used in everyday language, it usually means "something that causes a change." This definition is related to the scientific meaning of the word. In science, a catalyst speeds up the rate of a chemical reaction. Change happens when the chemical reaction occurs.

Many enzymes are affected by changes in temperature. Enzymes made by human cells usually work best at around 37° Celsius, or normal human body temperature. Enzymes also work best at certain pH values. For example, enzymes in the stomach work best in acidic solutions. Also, most enzymes are controlled by molecules that switch the enzymes "on" or "off" as needed.

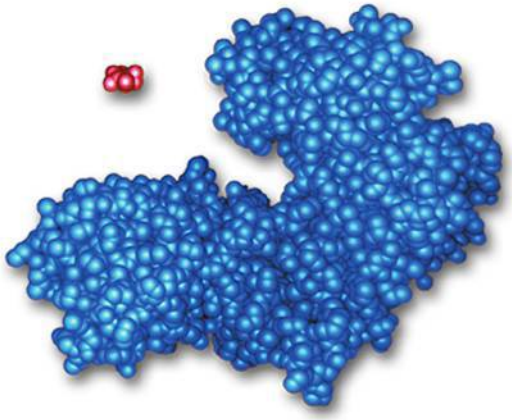
Key Question What role do enzymes play in living things and what affects their function? **Enzymes speed up chemical reactions that take place in cells. Temperature, pH, and other molecules can affect how enzymes work.**

BUILD Connections

UNLOCKING ENZYMES

The red molecule is a substrate and the blue molecule is the enzyme that it fits into. The gap in the enzyme is the active site. The fit between the enzyme and the substrate is like the fit between a lock and key.

In Your Workbook Go to your workbook to explain why a lock and key is a good analogy for a substrate and an enzyme.



CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. During a(n) _____, some chemical bonds are broken and others are formed.
2. A(n) _____ is a protein that speeds up reactions in living things.

Critical Thinking

3. **Use Analogies** A change in pH can change the shape of a protein. How might a change in pH affect the function of an enzyme? (**Hint:** Think about the lock and key analogy.)
4. **Compare and Contrast** Describe the difference between a reaction that often happens on its own and one that does not.
5. **Explain** Explain how enzymes work, including the role of the active site.
6. **Review** What happens to chemical bonds during chemical reactions?
7. **Apply Concepts** Why is the melting of ice not a chemical reaction?
8. **Write to Learn** Answer the third clue of the mystery. Consider how temperature might affect chemical reactions.

MYSTERY CLUE

The chemical reactions of living things happen more slowly at lower temperatures. How would very cold antarctic waters affect the ice fish's need for oxygen? (Hint: See above.)

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Pre-Lab: Temperature Affects Enzymes

Problem How does temperature affect the rate of an enzyme-catalyzed reaction?

Materials raw liver, forceps, petri dish, dropper pipette, 1% hydrogen peroxide solution, 25-mL graduated cylinder, 50-mL beaker, puréed liver, filter paper disks, paper towels, clock or watch with a second hand, water baths, thermometers, beaker tongs, graph paper

Lab Manual Chapter 2 Lab

Skills Focus Form a Hypothesis, Design an Experiment, Measure, Interpret Graphs

Connect to the Big idea Many chemical reactions in living organisms could not take place without enzymes. Enzymes catalyze the reactions that release energy from nutrients. They also catalyze the synthesis of the complex molecules that organisms need to grow and stay healthy. One factor that affects the action of enzymes is temperature. Think about why people store some foods in a refrigerator. The cold temperature limits the ability of enzymes to break down, or spoil, those foods.

Do high temperatures have the opposite effect on enzymes? Do they become more and more active as the temperature rises? In this lab, you will investigate the effect of temperature on an enzyme-catalyzed reaction.

Background Questions

a. **Review** Why do many reactions that occur in cells require enzymes? How do enzymes speed up chemical reactions?

b. **Review** Name three variables that can affect enzyme activity.

c. **Use Analogies** Use eggs and a frying pan on a stove as an analogy for reactants and an enzyme. Use the control knob on the stove burner as an analogy for how a variable can affect the action of an enzyme.

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Relate Cause and Effect** How will you know that a chemical reaction is taking place in Part A? How will you know in Part B?
2. **Control Variables** In Part B of the lab, which variable will you manipulate? Which variable is the dependent variable?
3. **Relate Cause and Effect** How is the time required for the filter-paper disk to float related to the activity of the enzyme?

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Visit Chapter 2 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Watch the Untamed Science crew find answers to the mystery of why water is such a special compound.

Art Review Learn about ionic and covalent bonding.

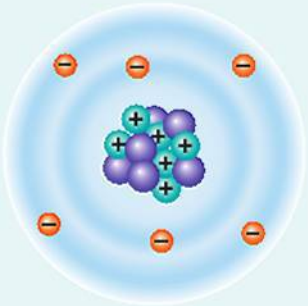
Art in Motion View an animation that shows the process of a salt crystal dissolving in water.

Visual Analogy Compare enzymes and substrates to a lock and key.

2 CHAPTER Summary

2.1 The Nature of Matter

- The particles that make up atoms are protons, neutrons, and electrons.
- All isotopes of an element have the same number of protons and the same chemical properties.
- The physical and chemical properties of a compound are usually very different from those of the elements that make it up.
- The main kinds of chemical bonds are ionic bonds and covalent bonds.



atom (p. 28)
nucleus (p. 28)
electron (p. 28)
element (p. 29)
isotope (p. 29)
compound (p. 30)
ionic bond (p. 30)
covalent bond (p. 31)
molecule (p. 31)

2.2 Properties of Water

- Water is a polar molecule. It is able to form many hydrogen bonds, which makes water cohesive and adhesive.
- Water's polar nature gives it the ability to dissolve both ionic compounds and other polar molecules.
- Buffers play an important role in maintaining homeostasis in organisms.

cohesion (p. 34)
adhesion (p. 34)
solution (p. 34)
suspension (p. 35)
acid (p. 36)
base (p. 36)
buffer (p. 36)

2.3 Carbon Compounds

- Carbon can bond with many elements, including hydrogen, oxygen, phosphorus, sulfur, and nitrogen, to form the molecules of life.
- Living things use carbohydrates as their main source of energy. Plants, some animals, and other living things also use carbohydrates for structural purposes.
- Lipids can be used to store energy. Some lipids are important parts of biological membranes and waterproof coverings.
- Nucleic acids store and transmit genetic information.
- Some proteins control cell processes and the rate of reactions. Others form important parts in cells, while still others move substances into or out of cells or help to fight disease.

carbohydrate (p. 38)
lipid (p. 39)
nucleic acid (p. 40)
protein (p. 40)
amino acid (p. 40)

2.4 Chemical Reactions and Enzymes

- During chemical reactions, some bonds are broken and other bonds are formed.
- Chemical reactions that give off energy often happen on their own. Chemical reactions that take in energy will not happen without a source of energy.
- Enzymes speed up chemical reactions that take place in cells.
- Temperature, pH, and other molecules can affect how enzymes work.

chemical reaction (p. 42)
activation energy (p. 43)
catalyst (p. 44)
enzyme (p. 44)

2 CHECK Understanding

Assess the Big idea Matter and Energy

Write an answer to the question below.
Q: What are the basic chemical principles that affect living things?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs long. To help you begin, read the **Hints** below each of the questions.

1. **How are chemical compounds related to the electrons in atoms?**

   Hint Chemical compounds are made when two or more elements are chemically joined.

   Hint Molecules of compounds are formed when atoms of elements form bonds with each other.

2. **How does the structure of a water molecule help water dissolve ionic compounds?**

   Hint The atoms in water are joined by covalent bonds.

   Hint The electrons in water are not evenly spread out.

3. **Explain which of the four groups of macromolecules are polymers and which are not.**

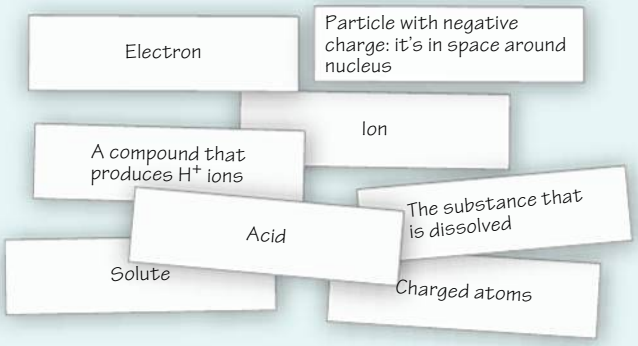
   Hint A polymer is a large compound made by the joining of many monomers.

Foundations for Learning Wrap-Up

Use the vocabulary quiz sheet that you made when you started the chapter as a tool to help you learn the important words from this chapter. Do Activity 1 before you do Activity 2.

Activity 1 Compare your quiz sheet with a partner's quiz sheet. If your partner's sheet has words that you do not have, add them to your own sheet. Fold the tabs over the definitions. Then, swap sheets with your partner and take turns quizzing each other on the definitions of the words. Open each word's matching tab as you ask your partner what the word means.

Activity 2 Cut your vocabulary quiz sheet so that the words and definitions are on separate slips of paper. Cut off the tabs. Discard the tabs. Mix up the remaining slips of paper on your desk. Then, work to match up each vocabulary word with its definition.



2.1 The Nature of Matter

Understand Key Concepts

1. The positively charged particle in an atom is a(n)
   a. electron. **c.** neutron.
   b. ion. **d.** proton.

2. Two or more atoms are joined in definite amounts in any
   a. compound. **c.** isotope.
   b. element. **d.** symbol.

3. A covalent bond is formed by the
   a. gaining of electrons.
   b. losing of electrons.
   c. sharing of electrons.
   d. transfer of electrons.

Test-Taking Tip

Choose Among Similar Answers The answers for question 3 all end with "of electrons," so those words will not matter when picking an answer. You have to look at only the first word of each answer. When you do, you should realize that "gaining" and "losing" are part of a "transfer" of electrons. So, answers **a**, **b**, and **d** are all related and cannot all be correct. So, answer **c** is the right answer.

Think Critically

4. **Compare and Contrast** Describe how ionic bonds and covalent bonds are similar and how they are different.

2.2 Properties of Water

Understand Key Concepts

5. When you put salt and water together in a beaker, you cause them to form a
   a. compound. **c.** mixture.
   b. solution. **d.** suspension.

6. A compound that releases hydrogen ions (H^+) in solution is a(n)
   a. acid. **c.** polymer.
   b. base. **d.** salt.

Think Critically

7. **Explain** Explain the properties of cohesion and adhesion. Then, give an example of each property.

8. **Apply Concepts** A student mixes a spoonful of sugar in a glass of water. Explain what the student has made using the terms *solution*, *solute*, and *solvent*.

2.3 Carbon Compounds

Understand Key Concepts

9. Proteins are polymers formed from
   a. amino acids.
   b. lipids.
   c. nucleic acids.
   d. simple sugars.

10. Carbohydrates are made up of all of the following elements EXCEPT
    a. carbon. **c.** oxygen.
    b. hydrogen. **d.** sodium.

Think Critically

11. **Apply Concepts** Explain the relationship between monomers and polymers using complex carbohydrates as an example.

12. **Explain** Describe the structure of a lipid and explain how to tell if the lipid is saturated or unsaturated.

2.4 Chemical Reactions and Enzymes

Understand Key Concepts

13. In a chemical reaction, a reactant binds to an enzyme at a place known as the
    a. active site. **c.** product.
    b. catalyst. **d.** substrate.

2 CHECK Understanding

14. An enzyme speeds up a reaction by
    - **a.** giving off energy.
    - **b.** taking in energy.
    - **c.** lowering the activation energy.
    - **d.** raising the activation energy.

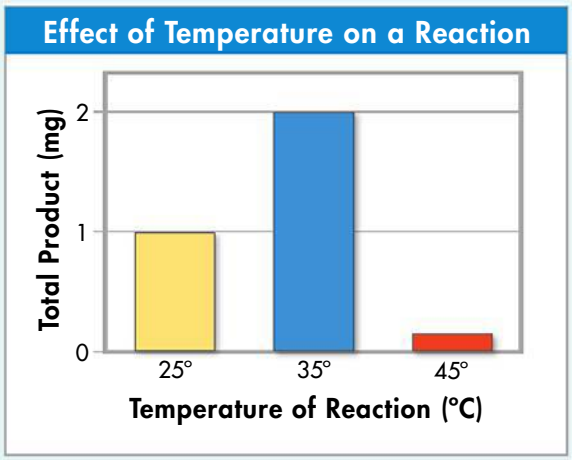
Think Critically

15. **Infer** An enzyme made by the human body is put in a solution in a lab. The temperature of the solution is 20°C. How would this temperature affect how the enzyme works? Explain your answer.
16. **Use Analogies** Explain why a lock and key are used to describe the way an enzyme works.

Connecting Concepts

Use Science Graphics

The following graph shows the total amount of product from a chemical reaction performed at three different temperatures. The same enzyme was involved in each case. Use the graph to answer questions 17–19.



17. **Interpret Graphs** At which temperature was the greatest amount of product formed?
18. **Draw Conclusions** Describe the results of each reaction. How can you explain these results?
19. **Predict** A student performs the same chemical reaction at 30°C. About how much product can she expect to get?

solve the CHAPTER MYSTERY

THE GHOSTLY FISH

The protein hemoglobin allows the blood of most fishes to carry nearly 50 times the oxygen it would without the protein. The ghostly white look of the antarctic ice fish comes from its clear blood—blood without hemoglobin. Ice fish can live without hemoglobin because of the properties of very cold water.

Oxygen dissolves in seawater, providing the oxygen that fishes need to live. Fishes take in dissolved oxygen directly through their gills, where it passes into their blood. More oxygen can dissolve in water when the water is cold. So, the icy cold antarctic waters have a lot of oxygen.

The large gills and scaleless skin of ice fish let them take in oxygen efficiently from the water. Compared to red-blooded fishes, ice fish have a higher blood volume, thinner blood, and larger hearts. Their blood can carry more dissolved oxygen. The large hearts can pump the thinner blood through the body faster. These and other physical features, along with the chemistry of oxygen in very cold water, enable ice fish to live where many other living things cannot.

1. **Relate Cause and Effect** Ice fish produce antifreeze proteins to keep their blood from freezing. Their body temperature stays below 0°C. How does low body temperature affect the blood's ability to carry dissolved oxygen?
2. **Infer** People living at high altitudes generally have more hemoglobin in their blood than people living at sea level. Why do you think this is so?
3. **Predict** If the antarctic oceans were to warm up, how might this affect ice fish?

UntamedScience Finding the solution to the fishy mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

Standardized Test Prep

Multiple Choice

1. The elements or compounds that enter into a chemical reaction are called
A products. **C** active sites.
B catalysts. **D** reactants.

2. Chemical bonds that involve the total transfer of electrons from one atom or group of atoms to another are called
A covalent bonds. **C** hydrogen bonds.
B ionic bonds. **D** oxygen bonds.

3. Which of the following is NOT a macromolecule found in living organisms?
A protein **C** sodium chloride
B nucleic acid **D** lipid

4. Which combination of particle and charge is correct?
A proton: positively charged
B electron: positively charged
C neutron: negatively charged
D electron: no charge

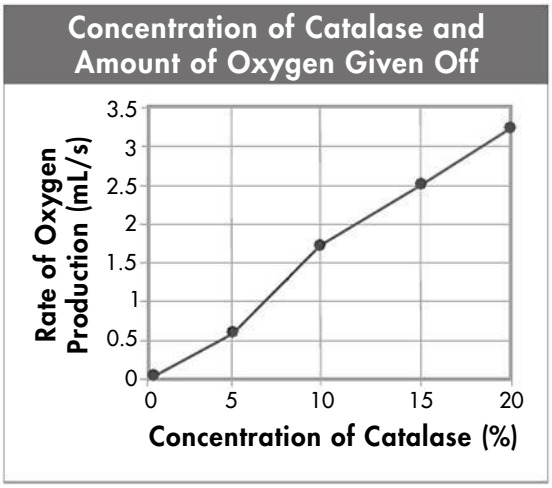
5. In which of the following ways do isotopes of the same element differ?
A in number of neutrons only
B in number of protons only
C in numbers of neutrons and protons
D in number of neutrons and in mass

6. Which of the following molecules is made up of glycerol and fatty acids?
A sugars
B starches
C lipids
D nucleic acids

7. Nucleotides consist of a phosphate group, a nitrogenous base, and a
A fatty acid.
B lipid.
C 5-carbon sugar.
D 6-carbon sugar.

Questions 8–9

The enzyme catalase speeds up the chemical reaction that changes hydrogen peroxide into oxygen and water. The amount of oxygen given off is an indication of the rate of the reaction.



8. Based on the graph, what can you conclude about the relationship between enzyme concentration and reaction rate?
A Reaction rate decreases with increasing enzyme concentration.
B Reaction rate increases with decreasing enzyme concentration.
C Reaction rate increases with increasing enzyme concentration.
D The variables are indirectly proportional.

9. Which concentration of catalase will produce the fastest reaction rate?
A 5% **C** 15%
B 10% **D** 20%

Open-Ended Response

10. List some of the properties of water that make it such a unique substance.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	2.4	2.1	2.3	2.1	2.1	2.3	2.3	2.4	2.4	2.2

UNIT 1

The Nature of Life

Unit Project

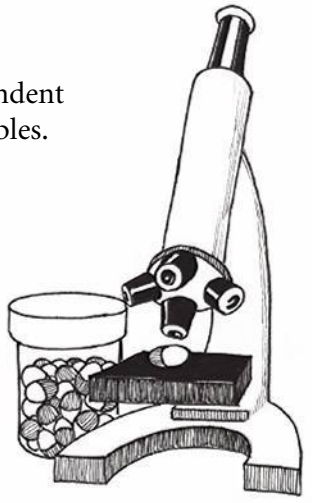
Design the Experiment

Did you ever wonder how a medication goes from the lab to your local drug store shelf? A lot of research and experimentation by scientists goes into testing a new medication to make sure it is safe and effective. Imagine you are a scientist working for a pharmaceutical company. Your current project is to test a new medication for heartburn. Heartburn is a painful condition in which acid inside the stomach backs up into the esophagus—the connection between your throat and stomach. This new medication helps neutralize stomach acid to prevent irritation.

Your Task Design *three* possible experiments to test the safety and effectiveness of the new heartburn medication. Before you begin, think about how you will know if the medication actually neutralizes stomach acid. Once you've written your procedures, you will propose the experiments to your company's Executive Board for Research and Development.

For each experiment,

- identify clear independent and dependent variables.
- identify a control.
- form a hypothesis—predict the results you'd expect to find if the medication worked.
- write a specific procedure that tests your hypothesis.



Reflection Questions

1. **Score your experimental designs using the rubric below. What score did you give yourself?**
2. **What did you do well in this project?**
3. **What about your designs needs improvement?**
4. **Are there any ethical dilemmas related to your experiments? Explain.**

Assessment Rubric

Score	Scientific Content	Quality of Experiments
4	Correctly and extensively applies knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.	Experimental designs are clever and effectively test the hypotheses. Experimental conditions are carefully controlled and variables are correctly identified.
3	Applies relevant knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.	Experimental designs are logical and test the hypotheses. Experimental conditions are controlled and variables are correctly identified.
2	Applies relevant knowledge and understanding of unit concepts (i.e., pH scale) incompletely to experimental designs and predictions.	Experimental designs need some revisions—some parts are unclear or do not fully test the hypotheses. Variables and controls need corrections.
1	Does not correctly apply knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.	Experimental designs are unclear and do not test the hypotheses. Variables and controls listed are incorrect or absent.

Ecology

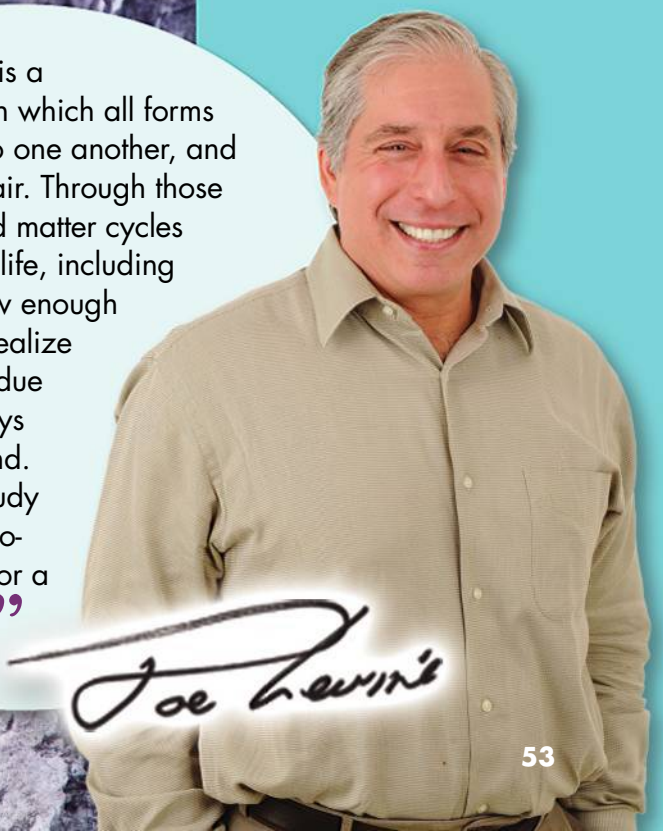
UNIT 2

Chapters

INTRODUCE the Big ideas

- **Matter and Energy**
- **Interdependence in Nature**

"Earth is a living planet on which all forms of life are linked to one another, and to land, water, and air. Through those links, energy flows and matter cycles in patterns that support life, including human society. We know enough about these patterns to realize that they are changing, due to human activity, in ways that we don't understand. Our challenge is to study our impact on the biosphere and plan for a healthy future."



Joe Levine

3 The Biosphere

Big ideas

Matter and Energy, Interdependence in Nature

Q: How do Earth's living and nonliving parts interact and affect the survival of organisms?

Great White Egret among some plants in the Florida Everglades

BIOLOGY.com Search Chapter 3 GO • Flash Cards

INSIDE:

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

CHANGES IN THE BAY

Marine life in Rhode Island's Narragansett Bay is changing. One clue to those changes comes from fishing boat captains. These captains now boast about catching bluefish in November—a month after bluefish used to head south for winter. But catches of winter flounder are not as plentiful as they once were.

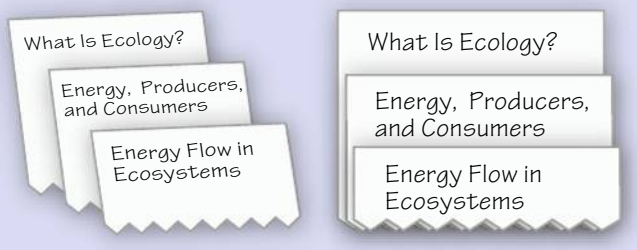
Other changes have also been observed in the bay. The annual spring increase in plant and animal growth is disappearing. Researchers working in the bay also report something puzzling. There are changes in the activities of bacteria living in mud on the bay floor.

What's going on? Farms, towns, and cities surround the bay. But direct human influence on the bay has not changed much lately. So why are there so many changes to the bay's plant and animal populations?

Read for Mystery Clues Could these changes be related to mud-dwelling bacteria? As you read the chapter, look for clues to help you understand the interactions of plants, animals, and bacteria in Narragansett Bay. Then, solve the mystery.

FOUNDATIONS for Learning

Make a layered book by stacking 4 sheets of paper together. Make sure that 2 to 3 cm of each page in the stack is visible. Label the top page What Is Ecology? Label the remaining pages with the titles of Lessons 2, 3, and 4. Write the major headings from each lesson on the pages. When you finish reading a section, write a summary of the section in your layered book. Remember to use your vocabulary words in your summaries.



3.1 What Is Ecology?

Key Questions

- ***What is ecology?***
- ***What are biotic and abiotic factors?***
- ***What methods are used in ecological studies?***

BUILD Understanding

Venn Diagram Make a Venn diagram that shows how the environment consists of biotic factors and abiotic factors. The diagram should also show how some components are truly a mixture of both. Use examples from the lesson.

In Your Workbook Go to your workbook for help completing the Venn diagram for Lesson 3.1.

Studying Our Living Planet

Science writer Lewis Thomas once wrote: "Viewed from the distance of the moon, the astonishing thing about the earth . . . is that it is alive." That sounds good. But what does it mean? In a scientific sense, how is Earth a "living planet"? And how do we study it?

Biologists use the term *biosphere* when they talk about life on a global scale. The **biosphere** consists of all life on Earth and all parts of the Earth where life exists. This includes land, water, and the atmosphere. The biosphere contains every organism, from underground bacteria to giant rain forest trees, even humans. It extends from about 8 kilometers above Earth's surface to as far as 11 kilometers below the surface of the ocean.

The Science of Ecology Organisms in the biosphere interact with each other. But they also interact with their surroundings, or environment. The study of these interactions is called **ecology.** Ecology is the scientific study of the interactions between organisms and their physical environment.

Organisms respond to each other and to their environments. Organisms also affect each other and change their environments. These interactions produce an ever-changing, or dynamic, biosphere.

Individual Organism

A **population** is a group of individuals that belong to the same species and live in the same area.

An assemblage of different populations that live together in a defined area is called a **community.**

Levels of Organization The kinds of questions that ecologists ask about the living environment can vary. The questions depend on the level at which the ecologist works.

Ecology and Economics Some people think that ecology doesn't really matter to people very much. But humans depend on ecological processes to produce many things we need, such as food and clean water. Food, water, and other things we need are often worth money. That's why ecology is linked to the field called economics. Economics is concerned with human interactions based on money or trade.

Levels of Organization Ecologists ask many questions about organisms and their environments. Some ecologists focus on the ecology of individual organisms. Others try to understand how interactions among organisms (including humans) influence our global environment. Ecological studies may focus on levels of organization that include those shown below.

Key Question What is ecology?

Ecology is the scientific study of interactions among organisms and between organisms and their physical environment.

BUILD Vocabulary

biosphere
a part of Earth in which life exists, including land, water, and air, or atmosphere

ecology
the scientific study of interactions among organisms and between organisms and their environment

population
a group of individuals of the same species that live in the same area

community
a group of different populations that live together in a defined area

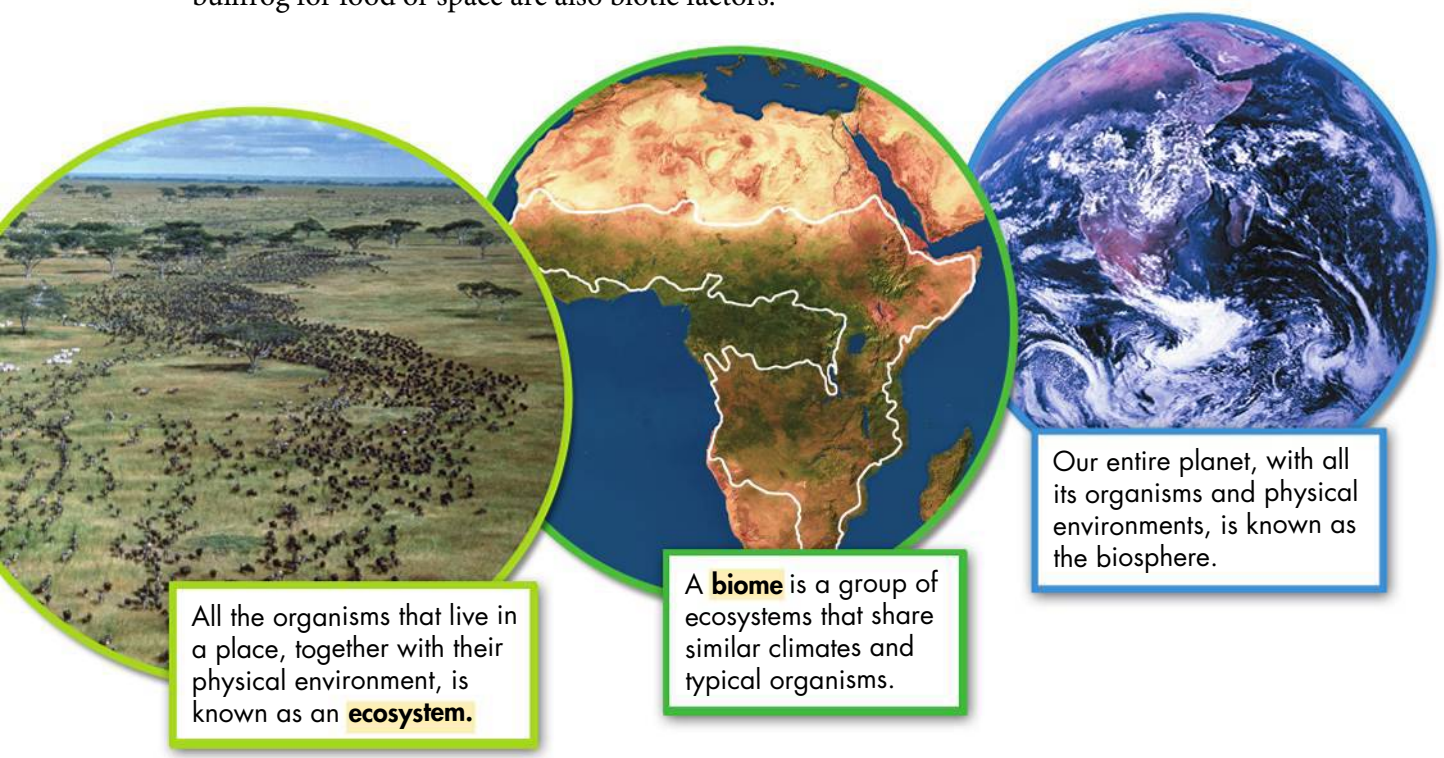
ecosystem
all the organisms that live in a place, together with their physical environment

biome
a group of ecosystems that share similar climates and typical organisms

Biotic and Abiotic Factors

Ecologists use the word *environment* to refer to all conditions, or factors, surrounding an organism. Environmental conditions include biotic factors and abiotic factors.

Biotic Factors A **biotic factor** is any living part of the environment. Biotic factors include animals, plants, mushrooms, and bacteria. For example, the insects that a bullfrog might eat are biotic factors. Another biotic factor relating to the bullfrog is the heron that might eat the bullfrog. Species that compete with the bullfrog for food or space are also biotic factors.



All the organisms that live in a place, together with their physical environment, is known as an **ecosystem.**

A **biome** is a group of ecosystems that share similar climates and typical organisms.

Our entire planet, with all its organisms and physical environments, is known as the biosphere.

BUILD Vocabulary

biotic factor
any living part of the environment with which an organism might interact

abiotic factor
a physical, or nonliving, factor that shapes an ecosystem

PREFIXES

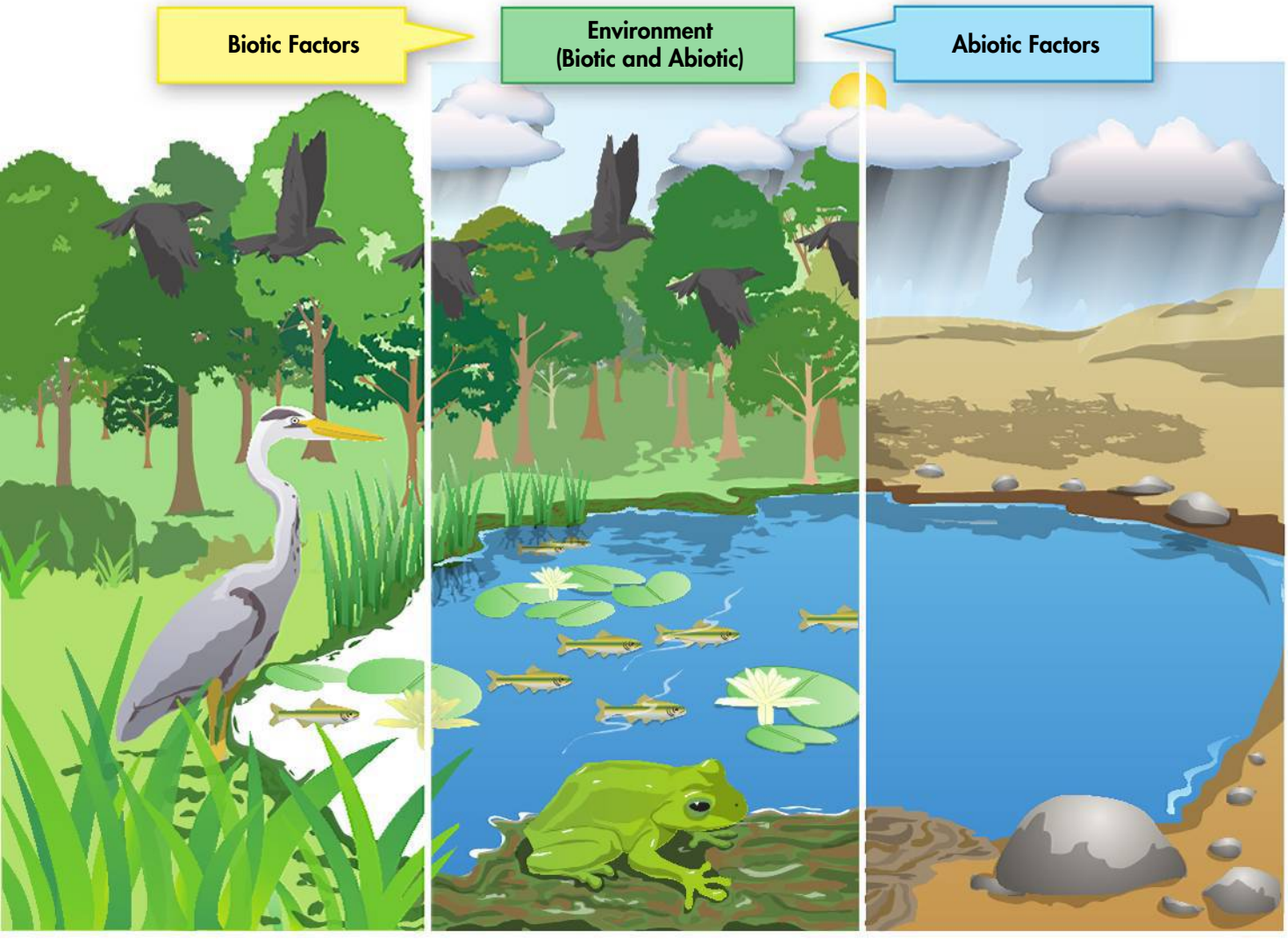
The prefix *bio-* comes from the Greek word *bios*, which means "living tissue."

Abiotic Factors An **abiotic factor** is any nonliving part of the environment. Abiotic factors include things like sunlight, precipitation, and water currents. For example, a bullfrog might be affected by water availability, temperature, and humidity.

Biotic and Abiotic Factors Together The difference between biotic and abiotic factors is not always simple. Many physical factors can be strongly influenced by the activities of organisms. Remember the bullfrog? It lives in soft "muck" along the shores of ponds. This muck is a mix of biotic factors such as bacteria and abiotic factors such as sand. Trees and shrubs around the pond affect the amount of sunlight that reaches its shoreline. Plant roots determine how much soil is held in place and how much washes into the pond. This kind of dynamic mix of biotic and abiotic factors shapes every environment.

Key Question What are biotic and abiotic factors?
Biological influences on organisms are called biotic factors. Physical elements of an ecosystem are called abiotic factors.

Biotic and Abiotic Factors
This pond is affected by a combination of biotic and abiotic factors.



Ecological Methods

Ecologists study many different parts of the biosphere and often use different research tools. But all ecologists use three scientific approaches to their work: observation, experimentation, and modeling.

Observation Observation is often the first step in asking ecological questions. Some observations are simple: Which species live here? Other observations are more complex: How does an animal protect its young from predators? These types of questions may form the first step in designing experiments and models.

Experimentation Experiments can be used to test hypotheses. Suppose an ecologist wants to see how growing plants react to different temperatures. He or she may set up an artificial environment in a greenhouse to test the plants' responses. Other experiments carefully alter conditions in selected parts of natural ecosystems.

Modeling Many ecological events occur over long periods of time or over large distances. These events are difficult to study directly. Ecologists make models to help them understand these events. These models are usually based on data collected through observation and experimentation. Then more observations are made to test predictions based on those models.

Key Question What methods are used in ecological studies?
Modern ecologists use three methods in their work: observation, experimentation, and modeling.

Ecology Field Work The three basic approaches to ecological research involve observing, experimenting, and modeling. This ecologist is measuring a Mediterranean tortoise.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The _____ extends from about 8 kilometers above the Earth's surface to as far as 11 kilometers below ocean's surface.
2. The science that studies all the interactions between living and nonliving parts of an ecosystem is called _____.
3. A herd of wildebeests living on the Serengeti Plain would be classified as a _____ within an ecosystem.

Critical Thinking

4. **Explain** Is weather a biotic or abiotic factor? Explain your answer.
5. **Compare and Contrast** How are biotic and abiotic factors related? How are they different?
6. **Write to Learn** Answer the first clue of the mystery. Write a paragraph that explains why you think the three abiotic factors you chose are important.

MYSTERY CLUE

What are three examples of abiotic factors that might affect life in the Narragansett Bay? (Hint: See p. 58.)

BIOLOGY.com Search Lesson 3.1 GO • Lesson Assessment

3.2 Energy, Producers, and Consumers

Key Questions

- ***What are primary producers?***
- ***How do consumers obtain energy and nutrients?***

BUILD Understanding

Concept Map As you read, use the highlighted vocabulary words to create a concept map that organizes the information in the lesson.

In Your Workbook Go to your workbook for help in completing your concept map.

Primary Producers

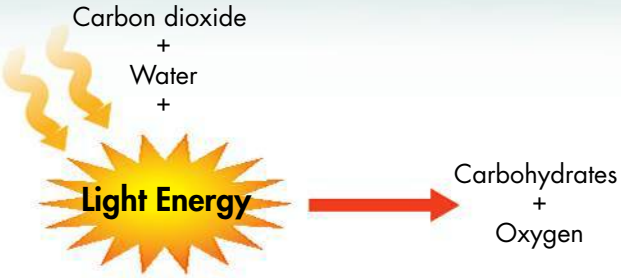
Organisms need energy for growth, reproduction, and their own metabolic processes. Without energy, there are no life functions!

No organism can create energy—organisms can only use energy from other sources. Where does that energy come from? Sunlight is the ultimate energy source for most life on Earth. But some organisms get their energy from chemical energy that is stored in inorganic chemical compounds.

Only algae, certain bacteria, and plants can capture energy from sunlight or chemicals. This energy is converted into forms that living cells can use. Such organisms are called **autotrophs.** They use solar or chemical energy to produce "food" by making organic molecules from inorganic compounds. Organisms that eat autotrophs use the energy stored in the bonds of these molecules. That's why autotrophs are also called **primary producers.** Primary producers are the first producers of energy-rich compounds that other organisms need to survive. Primary producers are essential to the flow of energy through the biosphere.

Energy From the Sun The most common primary producers capture solar energy through photosynthesis. Photosynthesis captures light energy and uses it to power chemical reactions. These reactions convert carbon dioxide and water into oxygen and energy-rich carbohydrates. Photosynthesis adds oxygen to the atmosphere and removes carbon dioxide. Without photosynthesis, there would not be enough oxygen for you to breathe! Plants are the main photosynthetic producers on land. Algae fill that role in freshwater ecosystems and in the sunlit upper layers of the ocean. Photosynthetic bacteria are the important primary producers in tidal flats and salt marshes.

Primary Producers Plants get energy from sunlight and turn it into nutrients. These nutrients can be eaten and used for energy by animals such as this caterpillar.



Photosynthesis

Photosynthesis
Plants use the energy from sunlight to carry out the process of photosynthesis. As a result, energy-rich carbohydrates are produced.

Life Without Light About 30 years ago, biologists found thriving ecosystems around deep-sea volcanic vents. Without light for photosynthesis, how did the primary producers capture energy? They used a process called chemosynthesis (kee moh SIN thuh sis) to harness energy from inorganic molecules. Chemosynthesis uses chemical energy to produce carbohydrates. Some chemosynthetic organisms live in hot springs while others live in tidal marshes.

Key Question What are primary producers?
Primary producers are the first producers of energy-rich compounds that are later used by other organisms.

Consumers

Animals, fungi, and many bacteria cannot capture energy directly from the environment. These organisms, called **heterotrophs** (HET uh roh trohfs), must get energy from other organisms by consuming them. So heterotrophs are also called **consumers.**

Types of Consumers Consumers are classified by the ways in which they acquire energy and nutrients. As you will see, the definition of *food* can vary quite a lot among different categories of consumers.

Beyond Consumer Categories The simple consumer categories often do not express how nature really works. For example, seeds and fruits are richer in nutrients and easier to digest than leaves. So herbivores that eat different plant parts need different types of digestive systems. Carnivores do not stay in their own categories, either. Hyenas are carnivores but will scavenge if they get a chance. This means it is important to understand how energy and nutrients move through ecosystems.

Key Question How do consumers obtain energy and nutrients?
Organisms that rely on other organisms for energy and nutrients are called consumers.

BUILD Vocabulary

autotroph
an organism that is able to capture energy from sunlight or chemicals and use it to produce its own food from inorganic compounds; also called a producer

primary producer
the first producer of energy-rich compounds that are later used by other organisms

heterotroph
an organism that obtains food by consuming other living things; also called a consumer

consumer
an organism that relies on other organisms for its energy and food supply; also called a heterotroph

PREFIXES
The prefix *auto-* means "by itself." The Greek word *trophikos* means "to feed." This means that an autotroph can be described as a "self feeder." It does not need to eat other organisms for food.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Consumers are classified as _____ because they are unable to make their own food.
2. Autotrophs are also known as _____ because they are the first organisms to produce energy-rich compounds in an ecosystem.

Critical Thinking

3. **Explain** How do consumers obtain energy?
4. **Compare and Contrast** How are detritivores different from decomposers? Give an example of each.
5. **Write to Learn** Answer the second clue of the mystery. Write a paragraph explaining the relationship between detritivores and decomposers in an ecosystem.

Bacteria are important members of the living community in Narragansett Bay. How do you think the bacterial communities on the floor of the bay might be linked to its producers and consumers? (Hint: See above.)

BIOLOGY.com Search Lesson 3.2 GO • Lesson Assessment • Art Review

3.3 Energy Flow in Ecosystems

Food Chains and Food Webs

What happens to energy stored in body tissues when one organism eats another? It moves from the "eaten" to the "eater." In every ecosystem, primary producers and consumers are linked through feeding relationships. There are many different feeding relationships in an ecosystem. But energy flows through the ecosystem in a one-way stream, from primary producers to various consumers.

Food Chains You can think of energy as passing through an ecosystem in a series of steps. This series of steps is called a **food chain.** In a food chain, organisms transfer energy by eating and being eaten. Food chains can vary in length. Look at the aquatic food chain below. The primary producers are a mixture of floating algae (called phytoplankton) and attached algae. These primary producers may be eaten by small fishes, such as flagfish. Larger fishes, like the largemouth bass, eat the small fishes. The bass are preyed upon by large wading birds, such as the anhinga. In the end, the anhinga may be eaten by an alligator. Therefore there are four steps in this food chain. So the top carnivore is four steps removed from the primary producer.

Food Webs In most ecosystems, feeding relationships are much more complicated than a simple chain can describe. One reason for this is that many animals eat more than one kind of food. Take Africa's Serengeti Plain, for example. Herbivores such as zebras, gazelles, and buffaloes often graze upon several different species of grasses. Several predators such as lions, hyenas, and leopards, in turn, often prey upon those herbivores! Ecologists call this network of feeding interactions a **food web.**

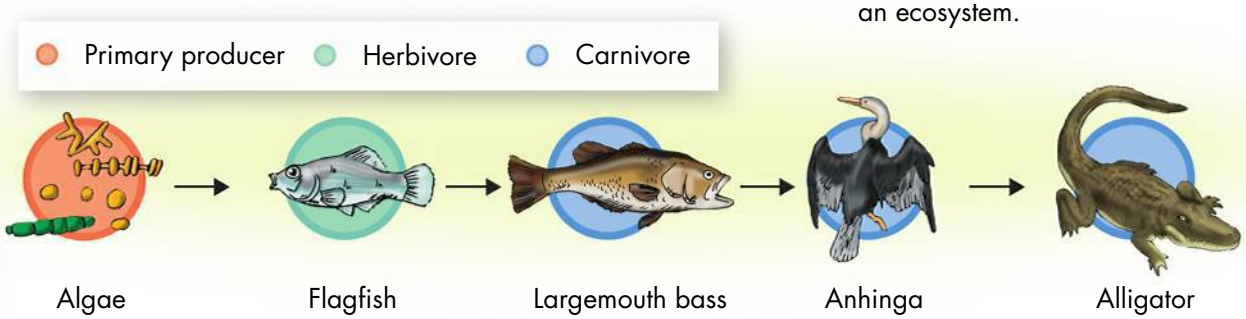
Key Questions

- ***How does energy flow through ecosystems?***
- ***What do the three types of ecological pyramids illustrate?***

BUILD Understanding

Preview Visuals Before you read, look at the diagrams called Food Chains and Food Web in the Everglades. Note how the diagrams are similar and how they are different.

In Your Workbook Complete the chart in Lesson 3.3 by noting the similarities and differences between the two diagrams.



Food Chains Food chains show the one-way flow of energy in an ecosystem.

BUILD Vocabulary

food chain
a series of steps in an ecosystem in which organisms transfer energy by eating and being eaten

food web
a network of complex interactions formed by the feeding relationships among the various organisms in an ecosystem

trophic level
each step in a food chain or food web

ecological pyramid
an illustration of the relative amounts of energy or matter contained within each trophic level in a given food chain or food web

ACADEMIC WORDS

An ecological pyramid looks more like a triangle than a pyramid. But ecologists call it a pyramid because it has layers that get smaller as you go toward the top—just like an Egyptian pyramid.

BUILD Connections

EARTH'S RECYCLING CENTER

Decomposers break down dead and decaying matter and release nutrients that can be reused by primary producers.

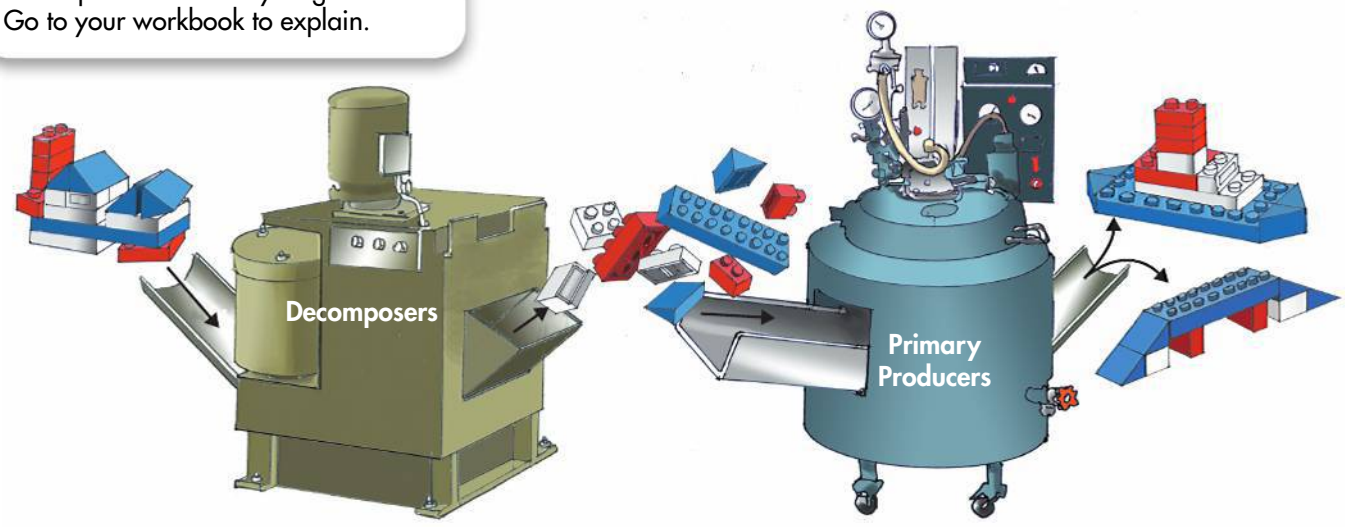
In Your Workbook How are decomposers like a recycling center? Go to your workbook to explain.

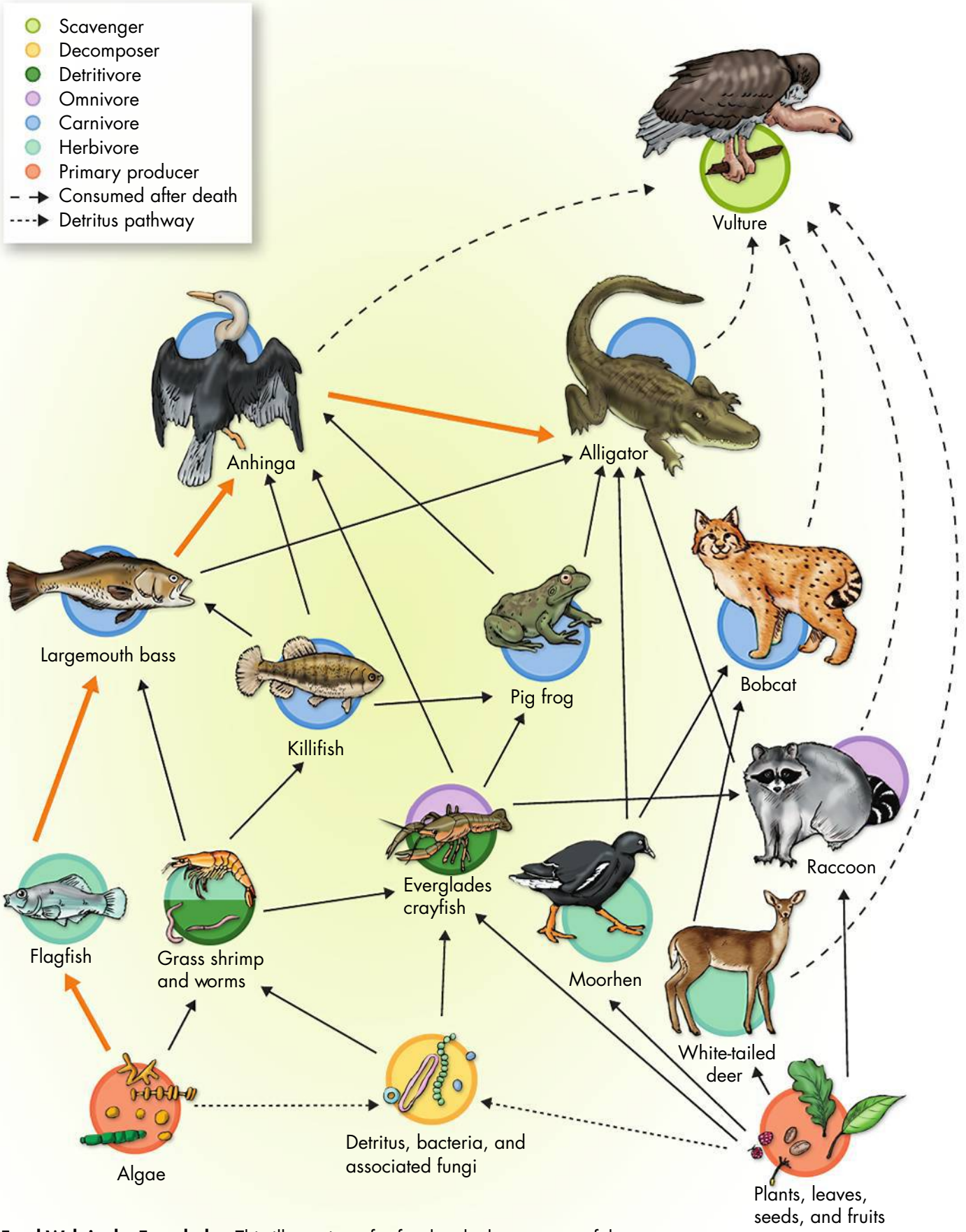
▶ ***Food Chains Within Food Webs*** The Everglades are a complex marshland ecosystem in southern Florida, with many overlapping feeding relationships. These relationships have been simplified —many species have been left out—and represented in the food web to the right. Many different paths can be taken from a primary producer to a predator. Each path is a food chain. So, a food web links together all of the food chains in an ecosystem. Now, you can begin to appreciate how complicated food webs are!

▶ ***Decomposers and Detritivores in Food Webs*** Decomposers and detritivores are as important in most food webs as other consumers are. Look again at the Everglades web. White-tailed deer, moorhens, raccoons, grass shrimp, crayfish, and flagfish feed at least partly on primary producers. But most producers die without being eaten, so decomposers convert that dead material to detritus. The detritus is eaten by detritivores, such as crayfish, grass shrimp, and worms. At the same time, the decomposition process releases nutrients that can be used by primary producers. Decomposers are nature's recyclers. Without decomposers, nutrients would remain locked in dead organisms.

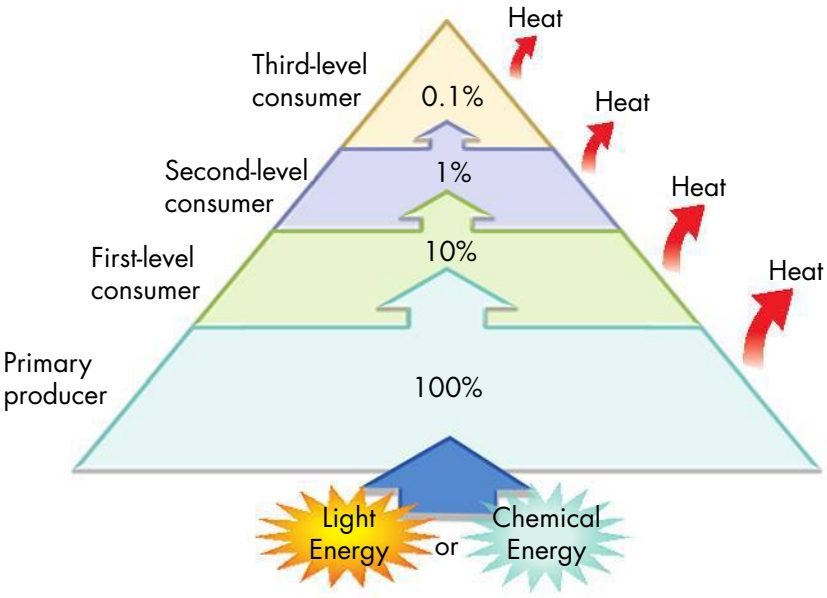
Food Webs and Disturbance Relationships in food webs are not simple, so a disturbance can have dramatic effects. Look again at the food web. What might happen to the feeding relationships in it after a disturbance? Suppose an oil spill caused a major decrease in the number of decomposers. How might that affect the populations of detritivores? Would a change in those populations affect how pig frogs feed? How might a change in frog feeding behavior affect other species the frogs eat? As you can see, a decrease in decomposers would affect the whole web.

Key Question How does energy flow through ecosystems? **Energy flows through an ecosystem in a one-way stream, from primary producers to various consumers.**





Food Web in the Everglades This illustration of a food web shows some of the feeding relationships within the Florida Everglades. The orange-highlighted aquatic food chain is one of many chains that make up this food web.



Pyramid of Energy An ecosystem must have a constant supply of energy from photosynthetic or chemosynthetic producers.

Ecological Pyramids

Each step in a food chain or food web is called a **trophic level.** Primary producers always make up the first trophic level. Various consumers occupy every other level. One way to illustrate the trophic levels in an ecosystem is with an ecological pyramid. **Ecological pyramids** show the relative amount of energy or matter within each trophic level of an ecosystem. There are three different types of ecological pyramids: pyramids of energy, pyramids of biomass, and pyramids of numbers.

Pyramids of Energy Theoretically, there is no limit to the number of trophic levels in a food web. There is also no limit to the number of organisms that live on each level. But each level only stores a small portion of the energy from the previous level. Organisms store this energy in their tissues. Much of the energy consumed is spent on life processes such as respiration and growth. Most of the remaining energy is released into the environment as heat. Pyramids of energy show the relative amount of energy available at each trophic level of a food chain or food web.

The efficiency of energy transfer from one trophic level to another varies. Typically, about 10 percent of the energy available within one level is transferred to the next. What happens when the number of levels between a producer and a consumer is large? The percentage of the original energy from producers available to the consumer is very small.

INQUIRY into Scientific Thinking

GUIDED INQUIRY

The 10 Percent Rule

The figure above shows an energy pyramid. An energy pyramid is a diagram that shows the transfer of energy through a food chain or food web. In general, only 10 percent of the energy available in one level is stored in the level above.

Analyze and Conclude

1. Calculate Suppose there are 1000 units of energy available at the producer level of the energy pyramid. Approximately how many units of energy are available to the third-level consumer? (Hint: Use the formula below.)

_____ units × _____% = _____ units of energy available

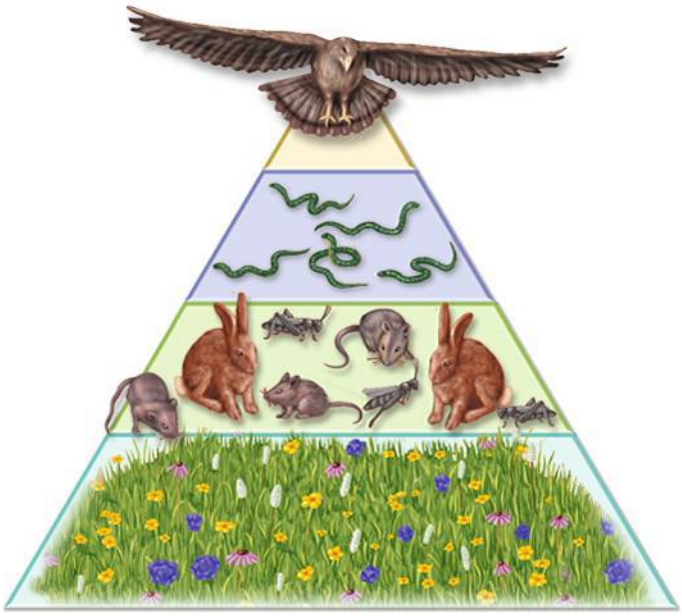
2. Interpret Diagrams What is the original source of the energy that flows through the ecosystem? Why must there be a continual supply of energy into the ecosystem?

In Your Workbook Get more help for this activity in your workbook.

Pyramids of Biomass and Numbers The total amount of living tissue within a trophic level is called its **biomass.** Biomass is usually measured in grams of organic matter per unit area. The amount of energy available to a trophic level helps determine the amount of biomass it can support. A pyramid of biomass illustrates the relative amount of living tissue available at each trophic level in an ecosystem.

Ecologists interested in the number of organisms at each trophic level use a pyramid of numbers. A pyramid of numbers shows the relative number of individual organisms at each trophic level in an ecosystem. Usually, the shapes of the pyramids of biomass and numbers are similar for an ecosystem. In this shape, the numbers of individuals on each level decrease from the level below it. The result might look something like the pyramid to the right.

In some cases, consumers are much smaller than the organisms they feed upon. For example, thousands of insects may graze on a single tree. Countless mosquitoes can feed off a few deer. Both the tree and deer have a lot of biomass, but they each represent only one organism. In such cases, the pyramid of numbers may be turned upside down, but the pyramid of biomass is right side up.



Pyramids of Biomass and Numbers In most cases, pyramids of biomass and numbers follow the same general pattern. In the field modeled here, there are more individual primary producers than first-level consumers. And the primary producers collectively have more mass. With each step to a higher trophic level, biomass and numbers decrease.

Key Question What do the three types of ecological pyramids illustrate? **A pyramid of energy shows the relative amounts of energy available at each trophic level of an ecosystem. A pyramid of biomass illustrates the relative amount of living organic matter available at each trophic level. A pyramid of numbers shows the relative number of organisms at each trophic level.**

BUILD Vocabulary

biomass the total amount of living tissue within a given trophic level

ACADEMIC WORDS

Mass is the amount of matter a substance or object has. The term *biomass* identifies a quantity of matter that is alive.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A(n) _____ is a way of representing the feeding relationships within an ecosystem.

2. A step in a food chain or food web is called a _____.

Critical Thinking

3. Write to Learn Answer the mystery clue.

MYSTERY CLUE

Zooplankton in Narragansett Bay graze on floating algae. The zooplankton now graze more actively during the winter than ever before. How might this affect the annual late-winter "bloom" of algae?

BIOLOGY.com Search Lesson 3.3 GO • Lesson Assessment

3.4 Cycles of Matter

Key Questions

- ***How does matter move through the biosphere?***
- ***How does water cycle through the biosphere?***
- ***What is the importance of the main nutrient cycles?***
- ***How does nutrient availability relate to the primary productivity of an ecosystem?***

BUILD Understanding

Main Idea and Details Chart
Make a main idea and details chart using the green and blue headings in this lesson. Fill in the details as you read to help you organize the information.

In Your Workbook Go to your workbook to learn more about making a main idea and details chart. Complete the chart for Lesson 3.4.

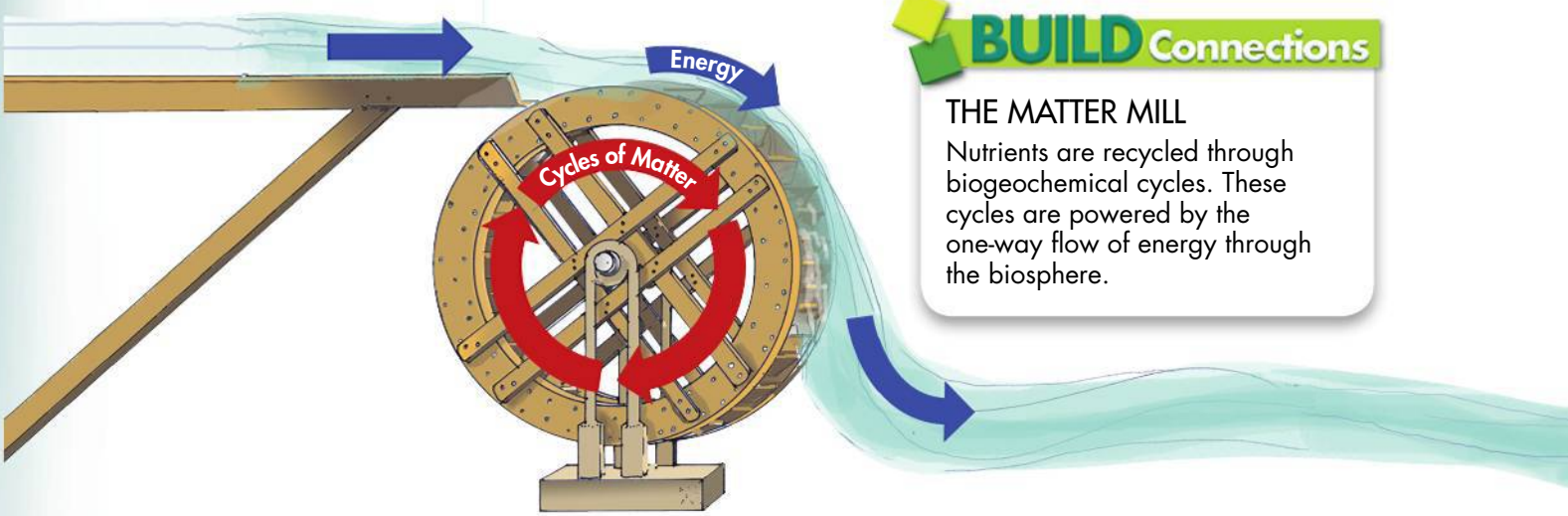
Recycling in the Biosphere

Energy passes in one direction from one trophic level to the next. Eventually it escapes into the environment as heat along the way. Energy in the form of sunlight is constantly entering the biosphere. But Earth doesn't receive a steady supply of new matter from space. Instead, matter is recycled. Elements, such as oxygen, carbon, and hydrogen, pass from one organism to another and from one ecosystem to another. They also pass among parts of the biosphere through closed loops called **biogeochemical cycles.** The flow of energy powers these cycles. Cycles of matter involve *bio*logical processes, *geo*logical processes, and *chemical* processes. Human activity can also play an important role. Matter is transformed as it moves through these cycles. It is never created or destroyed—just changed. The processes involved in biogeochemical cycles can be classified in the following ways:

▶ ***Biological Processes*** Biological processes consist of any and all activities performed by living organisms. These processes include eating, breathing, "burning" food, and eliminating waste products.

▶ ***Geological Processes*** Geological processes include volcanic eruptions and the formation and breakdown of rock. They also include major movements of matter within and below the surface of the earth.

▶ ***Chemical and Physical Processes*** Chemical and physical processes include the formation of clouds and precipitation. They also include the flow of running water and the action of lightning.



BUILD Connections

THE MATTER MILL
Nutrients are recycled through biogeochemical cycles. These cycles are powered by the one-way flow of energy through the biosphere.

▶ ***Human Activity*** Mining and burning fossil fuels, and burning forests, affect the cycles of matter. So does clearing land for building and farming. Manufacturing and using fertilizers also influence cycles of matter.

These cycles pass the same atoms and molecules around again and again. Just think—carbon atoms in your body may once have been part of the tail of a dinosaur!

Key Question How does matter move through the biosphere?
Matter is recycled within and between ecosystems.

The Water Cycle

Water constantly moves between the oceans, the atmosphere, and land. It can be inside organisms or outside them. Water molecules usually enter the atmosphere by evaporating from bodies of water or from plant leaves. When it evaporates, water becomes a gas called water vapor.

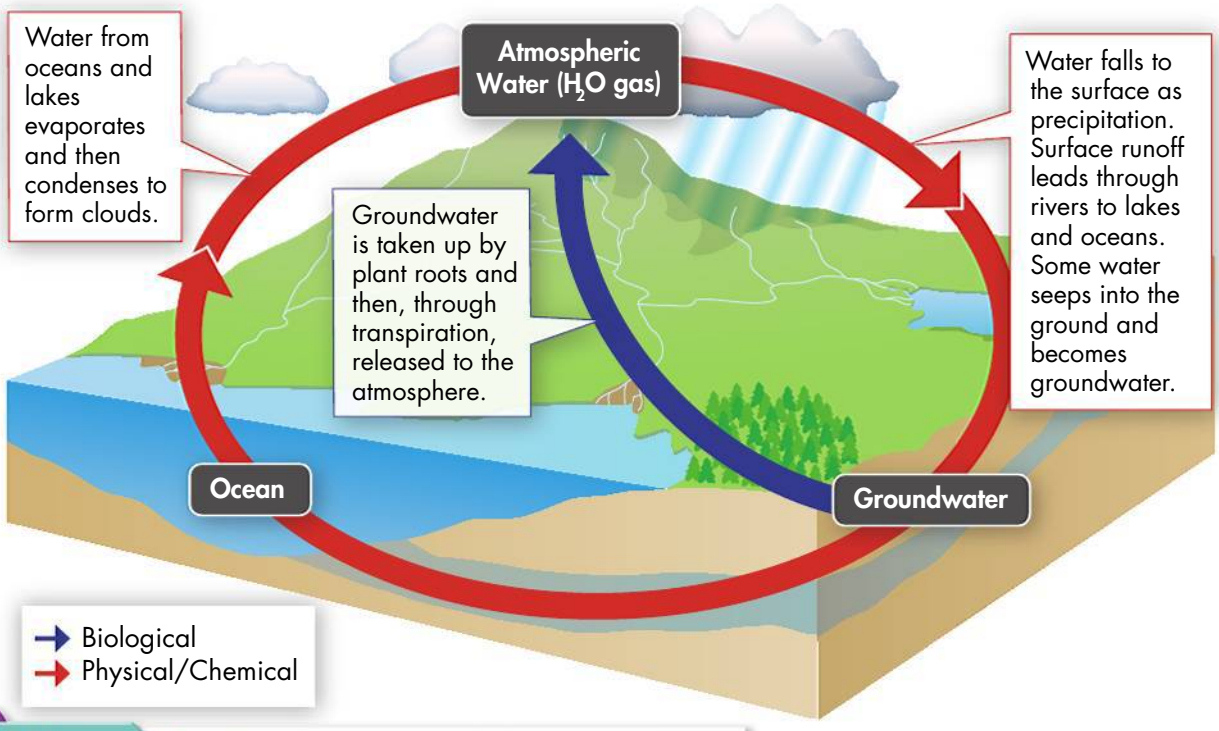
Winds can transport water vapor over great distances. In cooling air, the vapor condenses into tiny droplets that form clouds. When the droplets become large enough, they fall to Earth's surface as precipitation. This can be in the form of rain, snow, sleet, or hail. Precipitation can become runoff, flowing along the surface of land into a river or stream. It can also be absorbed into the ground, becoming groundwater. Groundwater enters plants through their roots or flows into bodies of water. If it penetrates deeply into the ground, it becomes part of underground reservoirs. Water that re-enters the atmosphere through transpiration or evaporation begins the cycle again.

Key Question How does water cycle through the biosphere?
Water continuously moves between the oceans, the atmosphere, and land. Sometimes the water is outside living organisms and sometimes it is inside them.

BUILD Vocabulary

biogeochemical cycle
a process in which elements, chemical compounds, and other forms of matter are passed from one organism to another and from one part of the biosphere to another

ROOT WORDS
The term *biogeochemical* is formed by combining the words *biological, geological,* and *chemical.*



The Water Cycle This diagram shows the main processes in the water cycle. Scientists estimate that it can take as long as 4000 years to complete one cycle.

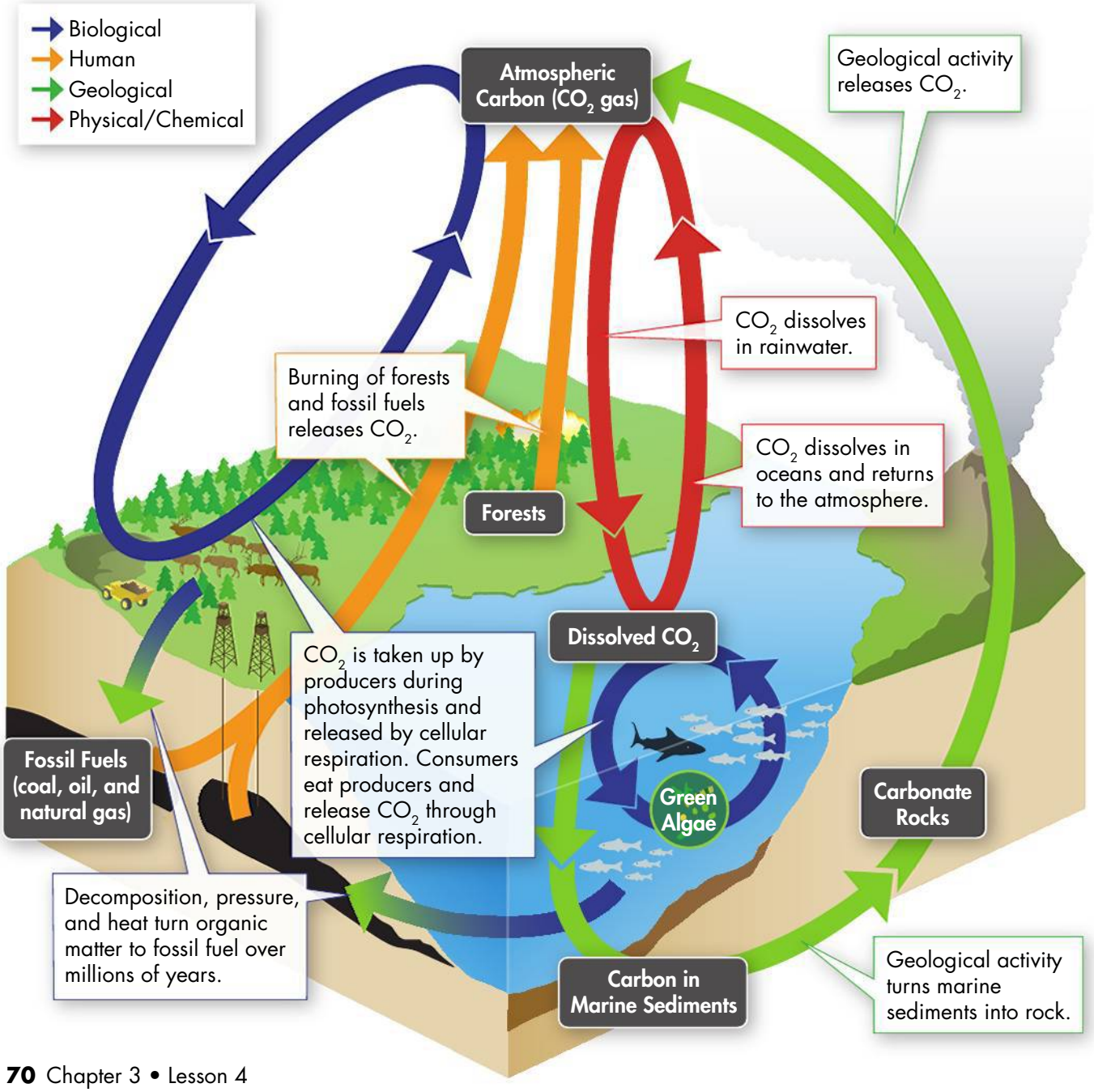
Nutrient Cycles

Nutrients are chemical substances organisms need to build tissues and carry out life functions. Like water, they pass through organisms and the environment through biogeochemical cycles. The three most important cycles move carbon, nitrogen, and phosphorus through the biosphere.

The Carbon Cycle Carbon is found in several large reservoirs in the biosphere. In the atmosphere, it is found as carbon dioxide gas (CO_2); in the oceans, as dissolved carbon dioxide; on land, in organisms, rocks, and soil; and underground, as coal, petroleum, and calcium carbonate.

The Carbon Cycle

Carbon is a major component of all organic compounds, including carbohydrates, lipids, proteins, and nucleic acids. There are several major carbon reservoirs in the biosphere. For example, carbon is found in calcium carbonate ($CaCO_3$). This mineral is found in animal skeletons and several kinds of rocks. Carbon and oxygen form carbon dioxide gas (CO_2). CO_2 is an important component of the atmosphere and is also dissolved in oceans. Coal, oil, natural gas, and forests also are important carbon reservoirs.



The figure to the left shows the carbon cycle. Notice how carbon often moves between different parts of the cycle as carbon dioxide. Stored carbon is found in organic matter, fossil fuels, rocks, and the skeletons of organisms.

The Nitrogen Cycle All organisms need nitrogen to make amino acids and nucleic acids. Nitrogen exists as a gas (N_2) in the atmosphere. Nitrogen compounds such as ammonia (NH_3), nitrate ions (NO_3^-), and nitrite ions (NO_2^-) are found in soil. These compounds also exist in wastes and decomposing organic matter. Several forms of dissolved nitrogen can be found in the oceans and other large water bodies.

Nitrogen gas is the most common form of nitrogen on Earth. But only certain kinds of bacteria can use nitrogen gas directly. These bacteria use a process called **nitrogen fixation** to convert nitrogen gas to ammonia. These bacteria live in the soil and on the roots of certain plants, such as peanuts and peas. Other kinds of soil bacteria convert ammonia into nitrates and nitrites. Primary producers use these compounds to make proteins and nucleic acids. Consumers eat producers and reuse the nitrogen to make their own proteins and nucleic acids. Decomposers release ammonia, nitrates, and nitrites from wastes and dead organisms. Producers can reuse these compounds. There are also some soil bacteria that convert nitrates to nitrogen gas. The process of converting nitrates to nitrogen gas is called **denitrification.** Denitrification provides the bacteria with energy. Humans also add nitrogen to the biosphere by manufacturing and using fertilizers. Runoff often carries excess fertilizer into surface water or groundwater.

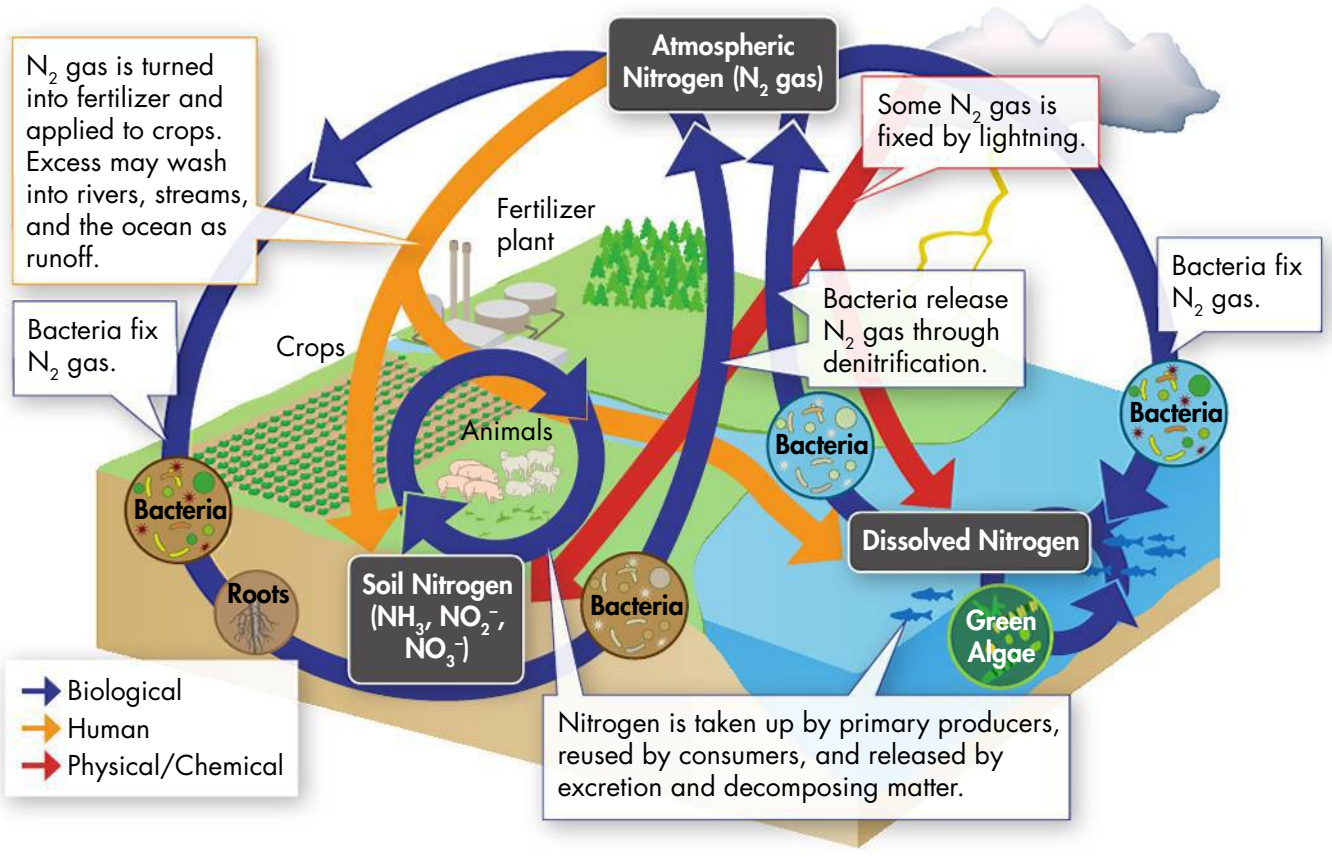
BUILD Vocabulary

nitrogen fixation
the process of converting nitrogen gas into nitrogen compounds that plants can absorb and use

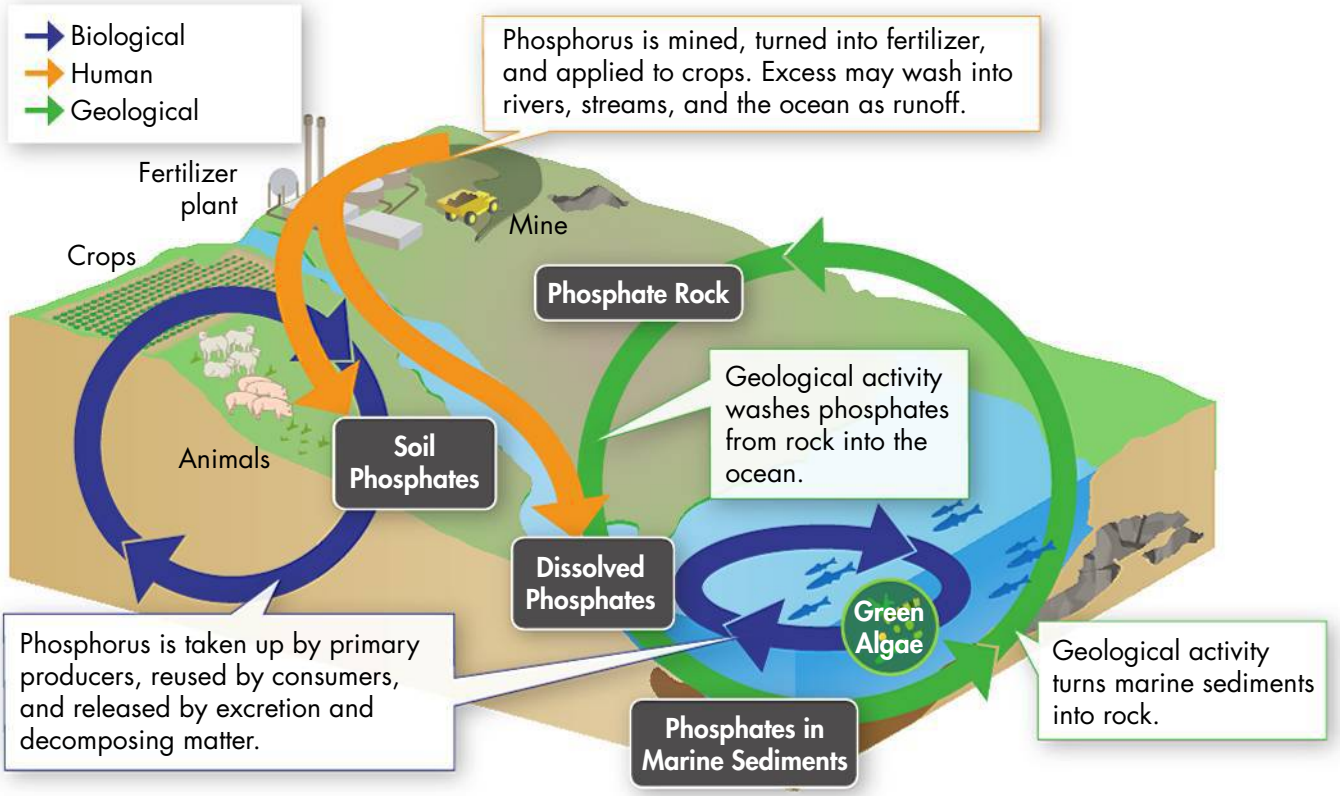
denitrification
the process by which soil bacteria convert nitrates into nitrogen gas

ACADEMIC WORDS

The verb *accumulate* means "to collect or gather." Carbon accumulates, or collects, in the soil and in the oceans where it cycles among organisms or is turned into fossil fuels.



The Nitrogen Cycle The atmosphere is the largest reservoir of nitrogen in the biosphere. Nitrogen also cycles through the soil and through the tissues of living organisms.



The Phosphorus Cycle Phosphorus in the biosphere cycles among the land, ocean, sediments, and living organisms. Unlike other nutrients, phosphorus is not found in significant quantities in the atmosphere.

The Phosphorus Cycle Phosphorus is essential to living organisms. It is an important part of molecules such as DNA and RNA. Although phosphorus is important biologically, it is not abundant in the biosphere. Phosphorus does not enter the atmosphere in large amounts. Phosphorus remains mostly on land and in the ocean as inorganic phosphate. On land it is found in phosphate rock and soil minerals. In the ocean, it may be dissolved or found in phosphate sediments.

Rocks and sediments release phosphate as they wear down. Some phosphate stays on land and cycles between organisms and soil. Plants bind phosphate into organic compounds when they absorb it from soil or water. Organic phosphate moves through the food web to the rest of the ecosystem. Other phosphate washes into rivers and streams, where it dissolves. This phosphate may eventually make its way to the ocean, where marine organisms process and incorporate it into biological compounds.

Key Question What is the importance of the main nutrient cycles?

Organisms need nutrients to build tissues and carry out life functions. The main nutrient cycles move carbon, nitrogen, and phosphorus through the biosphere.

Nutrient Limitation

Primary productivity is the rate at which primary producers create organic material. If even one essential nutrient in an ecosystem runs short, primary productivity will be limited. A nutrient whose supply limits productivity is called a *limiting nutrient*.

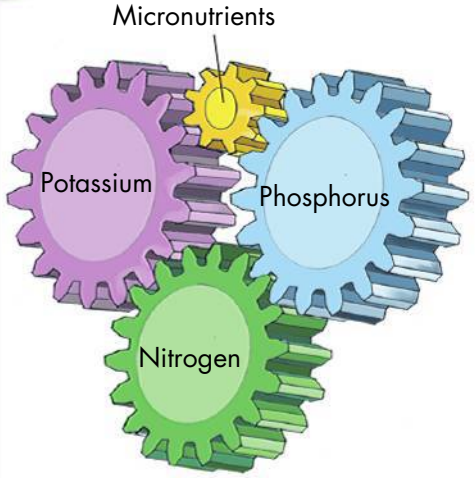
Nutrient Limitation in Soil On many farms, growth of crop plants is limited by a lack of one or more nutrients in the soil. That's why farmers use fertilizers! Most fertilizers contain large amounts of nitrogen, phosphorus, and potassium. These nutrients help plants grow better in poor soil. Micronutrients such as calcium, magnesium, sulfur, iron, and manganese are necessary in relatively small amounts. These elements are sometimes included in specialty fertilizers. Chemical fertilizers do not contain carbon. Plants get carbon from carbon dioxide during photosynthesis. All nutrient cycles work together like the gears in the figure to the right. If a nutrient runs short, the whole system slows down or even stops.

Nutrient Limitation in Aquatic Ecosystems The open oceans of the world are nutrient-poor compared to many land areas. In saltwater environments, nitrogen is typically the limiting nutrient. Phosphorus is typically the limiting nutrient in freshwater environments.

Sometimes an aquatic ecosystem receives a large input of a limiting nutrient. For instance, a heavy rain may cause runoff from heavily fertilized fields. The extra nutrients can cause a dramatic increase in the amount of algae and other primary producers. If there are not enough consumers to eat the algae, an algal bloom can occur. During an algal bloom, algae can cover the water's surface and disrupt the functioning of an ecosystem.

Key Question How does nutrient availability relate to the primary productivity of an ecosystem?
The availability of nutrients may limit primary productivity, even when sunlight and water are plentiful.

BUILD Connections



INTERLOCKING NUTRIENTS
The movement of each nutrient through ecosystems depends on the movement of all the others, because all are needed for living systems to function.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Bacteria convert nitrogen gas into ammonia using a process called _____.
2. Nutrients move between organisms, the atmosphere, the land, and the water in a series of processes called _____.

Critical Thinking

3. **Explain** How does the way that matter flows through an ecosystem differ from the way that energy flows?
4. **Relate Cause and Effect** A farmer plants a field of corn and fertilizes it with a low-nitrogen fertilizer. The corn receives plenty of sunlight and water, but does not grow well. What might be preventing the corn from growing?
5. **Write to Learn** Answer the fourth clue to the mystery. Think about how nitrogen enters the water. Is the increase in nitrogen in the water caused by nitrogen fixation or denitrification?

Recently, researchers discovered that levels of dissolved nitrogen in the bay have increased. Since human activity hasn't changed much, which organisms in the bay might be responsible? (Hint: See p. 71.)

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Real-World Lab

GUIDED INQUIRY

Pre-Lab: The Effect of Fertilizer on Algae

Problem How do excess nutrients affect the growth of algae?

Materials test tubes, test-tube rack, glass-marking pencil, dropper pipettes, algae culture, 25-mL graduated cylinder, spring water, plant food, cotton balls, grow light

Lab Manual Chapter 3 Lab

Skills Focus Predict, Compare and Contrast, Infer

Connect to the Big idea In a healthy ecosystem, nutrients cycle among primary producers, consumers, and decomposers. The growth of primary producers is limited by the availability of nutrients. Humans can intentionally increase the amount of nutrients in an ecosystem. For example, farmers may add fertilizer to the soil in which they grow crops. But the addition of nutrients to an ecosystem is not always planned. For example, runoff from soil that contains fertilizer may flow into coastal waters or freshwater ponds. In this lab, you will observe what happens when algae that live in those waters are provided with excess nutrients.

Background Questions

a. Review What is a limiting nutrient?

b. Explain Why do farmers use fertilizers?

c. Classify What role do algae play in freshwater ecosystems?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. Design an Experiment What is the independent variable in this experiment?

2. Predict After four days, how will you be able to tell which test tube has more algae?

3. Control Variables Why will you grow *Chlorella* in spring water instead of pond water?

BIOLOGY.com Search Chapter 3 GO

Visit Chapter 3 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Help the Untamed Science crew explore food relationships as they turn the ecological pyramid upside down.

Art in Motion View a short animation showing the different levels of organization.

Art Review Review your understanding of which organisms are producers and which are consumers with this drag-and-drop activity.

InterActive Art Build your understanding of the water cycle with this animation.

Tutor Tube Get some clarification on producers and consumers and learn how the flow of matter and energy is not what you may think!

Visual Analogies Compare a recycling center to decomposers in this activity. Compare nutrient limitation to a series of cogs in this activity.

3 CHAPTER Summary

3.1 What Is Ecology?

- Ecology is the scientific study of interactions among organisms and between organisms and their physical environment.
- A biotic factor is any living part of the environment.
- An abiotic factor is any nonliving part of the environment.
- Modern ecologists use three methods in their work: observation, experimentation, and modeling.

biosphere (p. 56)
ecology (p. 56)
population (p. 56)
community (p. 56)
biotic factor (p. 57)
abiotic factor (p. 58)

3.2 Energy, Producers, and Consumers

- Primary producers are the first producers of energy-rich compounds that are later used by other organisms.
- Organisms that rely on the other organisms for energy and nutrients are called consumers.

autotroph (p. 60)
primary producer (p. 60)
heterotroph (p. 61)
consumer (p. 61)

3.3 Energy Flow in Ecosystems

- Energy flows through an ecosystem in a one-way stream, from primary producers to various consumers.
- Pyramids of energy show the relative amount of energy available at each trophic level of an ecosystem. A pyramid of biomass illustrates the relative amount of living organic matter available at each trophic level. A pyramid of numbers shows the relative number of individual organisms at each trophic level.

food chain (p. 63)
food web (p. 63)
trophic level (p. 66)
ecological pyramid (p. 66)
biomass (p. 67)

3.4 Cycles of Matter

- Matter is recycled within and between ecosystems.
- Water continuously moves between the oceans, the atmosphere, and land. Sometimes the water is outside living organisms and sometimes it is inside them.
- Organisms need nutrients to build tissues and carry out life functions. The main nutrient cycles move carbon, nitrogen, and phosphorus through the biosphere.
- The availability of nutrients may limit primary productivity, even when sunlight and water are plentiful.

biogeochemical cycle (p. 68)
nitrogen fixation (p. 71)
denitrification (p. 71)

3 CHECK Understanding

Assess the Big idea Matter and Energy, Interdependence in Nature

Write an answer to the question below.
Q: How do Earth's living and nonliving parts interact and affect the survival of organisms?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each question should be one or two paragraphs. To help you begin, read the **Hints** below the questions.

1. **Why does the amount of energy available at each trophic level limit the number of organisms it can support?**

   Hint Only 10 percent of the energy from a given trophic level is transferred to the next trophic level.

   Hint Most of the energy transferred to a trophic level is used for life processes.

2. **How does a wildfire affect the carbon cycle?**

   Hint Trees are a part of an ecosystem's biomass.

3. **Why is it important for farmers to fertilize land used for crops?**

   Hint Primary productivity is limited by the availability of nutrients.

   Hint Which nutrients are found in high concentrations in plant material?

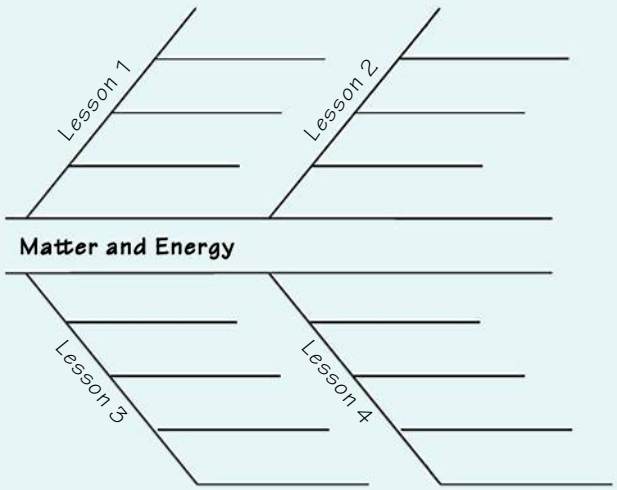
Foundations for Learning Wrap-Up

The summaries you wrote as you read the chapter are tools you can use to arrange your thoughts about the biosphere.

Activity 1 Working with a partner, take turns explaining the important concepts in each lesson using your summaries.

Activity 2 Working in small groups, create two fishbone maps like the one shown below. One map will represent Matter and Energy. The second map will focus on Interdependence in Nature. Fill in the maps with details from your summaries. Use the maps to answer the following questions:

- How do plants and animals interact to move matter and energy through the biosphere?
- How do the biogeochemical cycles interact to move matter and energy between land, water, and air?



3.1 What Is Ecology?

Understand Key Concepts

1. The term that ecologists use to indicate life on a global scale is
   - **a.** ecosystem.
   - **b.** biome.
   - **c.** biosphere.
   - **d.** ecology.

2. Which term describes a group of different species that live together in a defined area?
   - **a.** a population
   - **b.** a community
   - **c.** an ecosystem
   - **d.** a biosphere

Test-Taking Tip

Anticipate the Answer Think of your answer before looking at the answer choices. Then select the answer choice that comes closest to your own. In question 2, answer **b** is correct because a community is the only term that includes different species in a specific area.

Think Critically

3. **Pose Questions** You live near a pond that you have observed for years. One year you notice the water contains a massive overgrowth of green algae. What is a question you might have about this unusual growth?

3.2 Energy, Producers, and Consumers

Understand Key Concepts

4. Primary producers are organisms that
   - **a.** rely on other organisms for their energy and food supply.
   - **b.** consume plant and animal remains and other dead matter.
   - **c.** use energy from the environment to make complex organic molecules from inorganic molecules.
   - **d.** obtain energy by eating only plants.

5. Which of the following organisms is a decomposer?

a. 

c. 

b. 

d. 

6. Which of the following describes how ALL consumers get their energy?
   - **a.** directly from the sun
   - **b.** from eating primary producers
   - **c.** from inorganic chemicals like hydrogen sulfide
   - **d.** from eating organisms that are living or were once living

Think Critically

7. **Classify** Classify each of the following as an herbivore, a carnivore, an omnivore, or a detritivore: earthworm, bear, cow, snail, snake, human.

3.3 Energy Flow in Ecosystems

Understand Key Concepts

8. The series of steps in which a large fish eats a small fish that has eaten algae is a
   - **a.** food web.
   - **b.** food chain.
   - **c.** pyramid of numbers.
   - **d.** pyramid of biomass.

9. The total amount of living tissue at each trophic level in an ecosystem can be shown in a(n)
   - **a.** energy pyramid.
   - **b.** pyramid of numbers.
   - **c.** biomass pyramid.
   - **d.** biogeochemical cycle.

10. What happens to energy in a trophic level that is not stored or used for life processes?

Think Critically

11. **Sequence** Describe a food chain of which you are a member. You may draw or use words to describe the chain.

3 CHECK Understanding

3.4 Cycles of Matter

Understand Key Concepts

12. Nutrients move through an ecosystem in
- **a.** biogeochemical cycles.
- **b.** water cycles.
- **c.** energy pyramids.
- **d.** ecological pyramids.

13. List two ways in which water enters the atmosphere in the water cycle.

14. What is meant by "nutrient limitation"?

Think Critically

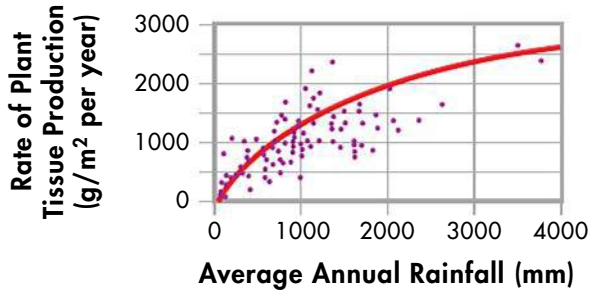
15. Infer Ecologists discovered that trout were dying in a stream that ran through some farmland. Nitrogen fertilizer had been used on the crops growing on this farmland. What do you think happened in the stream that caused the fish to die?

Connecting Concepts

Use Science Graphics

The graph below shows the effect of annual rainfall on the rate of primary productivity in an ecosystem. Use the graph to answer questions 16 and 17.

The Effect of Rainfall on Plant Productivity



16. Interpret Graphs What happens to productivity as rainfall increases?

17. Apply Concepts What factors other than water might affect primary productivity?

solve the CHAPTER MYSTERY

CHANGES IN THE BAY

One hypothesis suggests that rising water temperatures have caused most of the changes in Narragansett Bay. The bay's temperature has risen more than 1.5°C (3°F) since 1960. This warmth encourages bluefish to stay in the bay later in the fall. It also allows predatory warm-water shrimp to remain in the bay all winter. These shrimp feed on baby flounder. Warmer water also enables zooplankton to graze heavily on marine algae. This stops the late-winter algal bloom. The algal bloom used to provide organic carbon to the entire food web.

The result of these changes seems to be a shift in the activities of bacteria. The bacteria are responsible for transforming nitrogen. When the spring bloom provided organic carbon, bacteria denitrified the water. This released nitrogen into the atmosphere. Now, the bacterial community has changed and actually fixes nitrogen. This brings more of it into the water. No one knows how this will affect the long-term health of the bay and coastal waters.

1. Compare and Contrast In one paragraph, compare the way the bay used to be with the way the bay is now. Be sure to include changes in the food web and nitrogen cycle.

2. Infer Narragansett Bay harbors sea jellies that prefer warm water and have previously been present only in summer and early fall. These sea jellies eat fish eggs, fish larvae, and zooplankton. If the bay continues to warm, what do you think might happen to the population of sea jellies in the bay?

UntamedScience™ Finding out about Narragansett Bay is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

Standardized Test Prep

Multiple Choice

1. A group of individuals that belong to a single species and that live together in a defined area is termed a(n)
A population. **C** community.
B ecosystem. **D** biome.

2. Which of the following is NOT true about matter in the biosphere?
A Matter is recycled in the biosphere.
B Biogeochemical cycles transform and reuse molecules.
C The total amount of matter decreases over time.
D Water and nutrients pass between organisms and the environment.

3. Which is a source of energy for Earth's living things?
A wind energy only
B sunlight only
C wind energy and sunlight
D sunlight and chemical energy

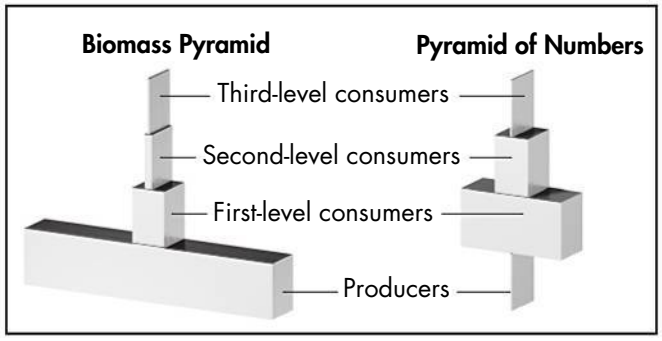
4. Which of the following is a primary producer?
A a producer, like algae
B a carnivore, like a lion
C an omnivore, like a human
D a detritivore, like an earthworm

5. Human activities, such as the burning of fossil fuels, move carbon through the carbon cycle. Which other processes also participate in the carbon cycle?
A biological processes only
B geochemical processes only
C chemical processes only
D a combination of biological, geological, and chemical processes

6. What are the physical, or nonliving components of an ecosystem called?
A abiotic factors
B temperate conditions
C biotic factors
D antibiotic factors

Questions 7–8

The diagrams below represent the amount of biomass and the numbers of organisms in an ecosystem.



7. What can you conclude about the ecosystem from the pyramid of numbers shown?
A There are more first-level consumers than producers.
B There are more third-level consumers than second-level consumers.
C There are more producers than first-level consumers.
D There are more second-level consumers than first-level consumers.

8. What can you conclude about the producers in the ecosystem based on the two pyramids shown?
A The producers in the ecosystem are probably very small organisms.
B There are no producers in the ecosystem.
C The producers in the ecosystem are probably large organisms.
D Decomposers in the ecosystem outnumber the producers in the ecosystem.

Open-Ended Response

9. What ultimately happens to the bulk of matter in any trophic level of a biomass pyramid—that is, the matter that does not get passed to the trophic level above?

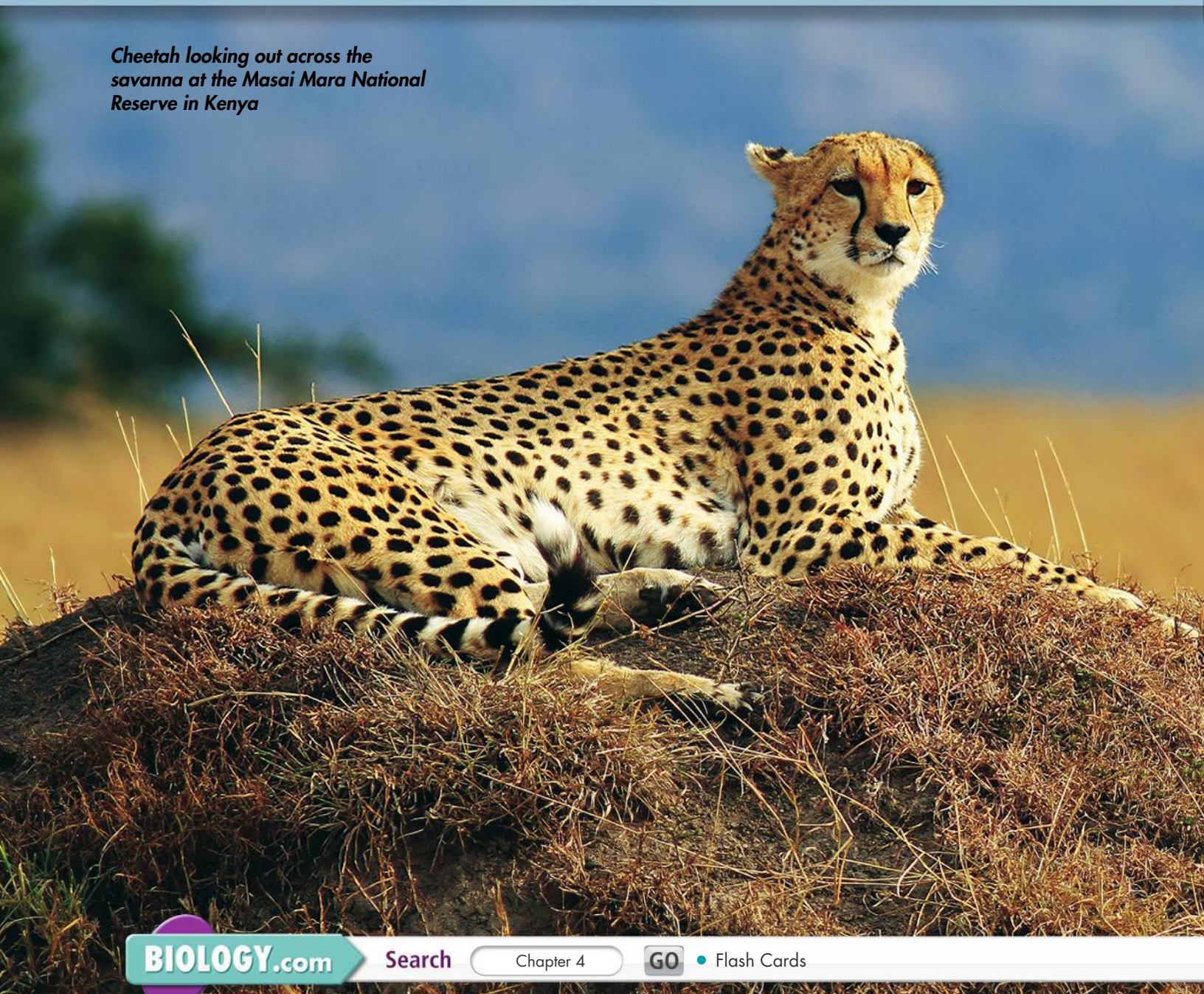
If You Have Trouble With . . .									
Question	1	2	3	4	5	6	7	8	9
See Lesson	3.1	3.4	3.2	3.2	3.4	3.1	3.3	3.3	3.3

4 Ecosystems and Communities

Big idea

Interdependence in Nature

Q: How do abiotic and biotic factors shape ecosystems?



Cheetah looking out across the savanna at the Masai Mara National Reserve in Kenya

BIOLOGY.com Search Chapter 4 GO • Flash Cards

INSIDE:

- 4.1 Climate
- 4.2 Niches and Community Interactions
- 4.3 Succession
- 4.4 Biomes
- 4.5 Aquatic Ecosystems

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

THE WOLF EFFECT

During the 1920s, hunting and trapping eliminated wolves from Yellowstone National Park. For decades, ecologists hypothesized that the loss of wolves had changed the park ecosystem. Wolves are important predators of elk and other large grazing animals. But there were no before-and-after data, so it was impossible to test that hypothesis directly.

Then, in the mid-1990s, wolves were reintroduced to Yellowstone. Researchers watched park ecosystems carefully. Soon, the number of elk in parts of the park began to fall just as predicted. But, unpredictably, forest and stream communities have changed, too. Could a "wolf effect" be affecting organisms in the park's woods and streams?

Read for Mystery Clues As you read this chapter, look for connections among Yellowstone's organisms and their environment. Then, solve the mystery.

FOUNDATIONS for Learning

Before you read the chapter, write each vocabulary word on an index card. As you read the chapter, write down the definition of each term on the back of the card in your own words. You can put the cards in categories to help you remember the definitions. Make a second set of cards containing the different types of ecosystems. At the end of the chapter are two activities that use the cards to answer the question: How do abiotic and biotic factors shape ecosystems?

4.1 Climate

Key Questions

- ***What is climate?***
- ***What factors determine global climate?***

BUILD Understanding

Preview Visuals Before you read, look at the Climate Zones diagram. What does it tell you about how the heat from the sun affects Earth's climates?

In Your Workbook Go to your workbook for more help with previewing visuals.

BUILD Vocabulary

climate
the average year-to-year conditions of temperature and precipitation in an area over a long period of time

microclimate
environmental conditions within a small area that differ significantly from the climate of the surrounding area

greenhouse effect
the process in which certain gases (carbon dioxide, methane, and water vapor) trap sunlight energy in Earth's atmosphere as heat

PREFIXES
The prefix *hemi-* in *hemisphere* means "half." The Northern Hemisphere is the northern half of Earth.

Weather and Climate

When you think of climate, you might think of major storms like Hurricane Katrina or a drought in the southeastern states. But, big storms and seasonal droughts are better described as weather instead of climate. So, what is climate and how is it different from weather? How do climate and weather affect organisms and ecosystems?

Weather and climate both involve variations in temperature, precipitation, and other environmental factors. Weather is the day-to-day condition of Earth's atmosphere. Weather where you live may be clear and sunny one day but rainy and cold the next. **Climate** refers to average conditions over long periods of time. A region's climate is defined by year-after-year patterns of temperature and precipitation.

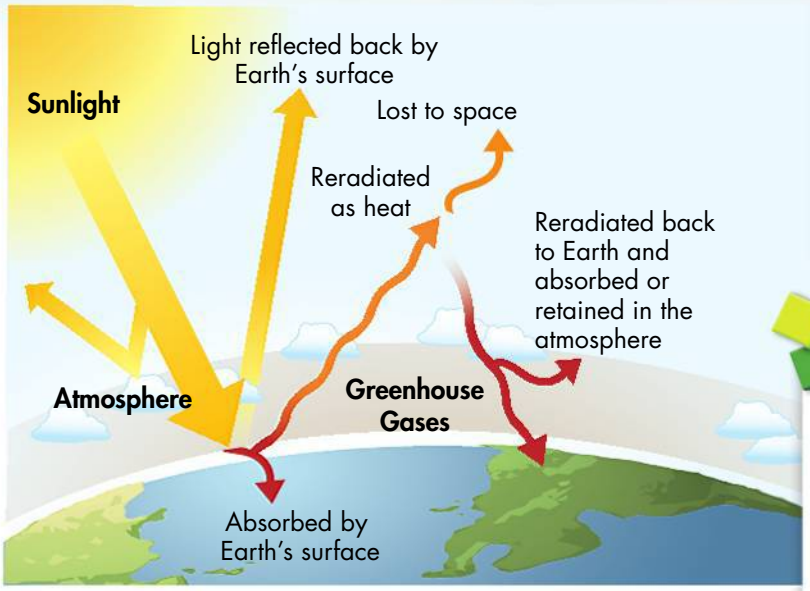
However, environmental conditions can vary over small distances, creating **microclimates.** For example, south-facing sides of trees and buildings in the Northern Hemisphere receive more sunlight. They are often warmer and drier than north-facing sides. These differences can be very important to many organisms.

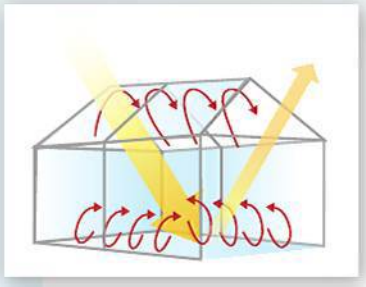
Key Question What is climate?
A region's climate is defined by year-after-year patterns of temperature and precipitation.

Factors That Affect Climate

What causes differences in climate? Global climate is shaped by many factors, including solar energy trapped in the biosphere. Latitude and the transport of heat by winds and ocean currents also help shape global climate.

Solar Energy and the Greenhouse Effect The main force that shapes our climate is solar energy that arrives as sunlight and strikes Earth's surface. Some solar energy is reflected back into space, and some is absorbed and converted into heat. Some of that heat radiates back into space, and some is trapped in the biosphere. The balance between heat that stays in the biosphere and heat lost to space determines Earth's average temperature. This balance is largely controlled by the concentrations of carbon dioxide, methane, and water vapor in the atmosphere. These gases are called greenhouse gases.





BUILD Connections

THE GREENHOUSE EFFECT

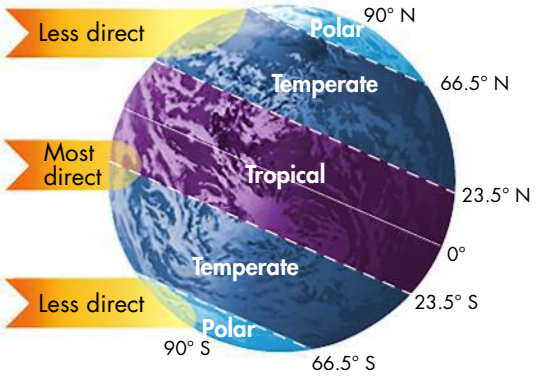
Greenhouse gases in the atmosphere allow solar radiation to enter the biosphere. But they slow down the radiation of Earth's heat back to space.

In Your Workbook Go to your workbook to explore the greenhouse analogy further.

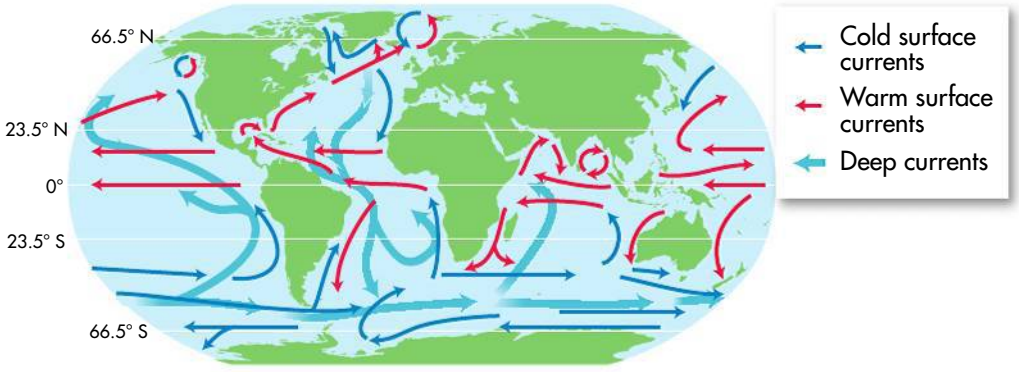
Greenhouse gases act like the glass in a greenhouse. The glass allows visible light to enter but traps heat. This effect is called the **greenhouse effect.** If greenhouse gas concentrations rise, they trap more heat, warming Earth. If their concentrations fall, more heat escapes, cooling Earth. Without the greenhouse effect, Earth would be about 30° Celsius cooler than it is today.

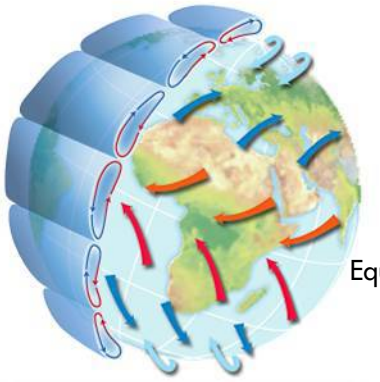
Latitude and Solar Energy Near the equator, solar energy is intense because the sun is almost directly overhead at noon all year. But this same amount of solar energy is spread out over a much larger area near the poles than near the equator. This spreading is caused by the curvature of the Earth. So Earth's polar areas annually receive less intense solar energy, and therefore heat, from the sun. This difference in heat distribution creates three different climate zones: tropical, temperate, and polar.

The tropical zone (tropics) includes the areas near the equator. The tropical zone receives nearly direct sunlight all year. It is located between 23.5° north and 23.5° south latitudes. The two temperate zones are on either side of the tropical zone between 23.5° and 66.5° north and south latitudes. Beyond the temperate zones are the polar zones, between 66.5° and 90° north and south latitudes. Temperate and polar zones receive very different amounts of solar energy at different times of the year. This variation is because Earth's axis is tilted. The tilt causes solar radiation to strike the Earth at an angle. The angle varies from summer to winter as the Earth revolves around the sun. During winter in the temperate and polar zones, the sun is much lower in the sky. The days are also shorter, and solar energy is less intense.



Climate Zones Earth's climate zones are produced by unequal distribution of the sun's heat on Earth's surface. Polar regions receive less solar energy per unit area than tropical regions. This means they receive less heat, too. The tilt of Earth's axis causes the distribution of sunlight to change over the course of the year.





Winds and Currents Earth's winds (above left) and ocean currents (above right) interact to help produce climate patterns. The paths of winds and currents are the result of heating and cooling, Earth's rotation, and geographic features.

Heat Transport in the Biosphere The difference in the amount of heat between the tropics and the poles creates wind and ocean currents. These currents transport heat and moisture. When air is heated in warm areas such as the tropics, it expands. This warm air is less dense, so it rises. After it rises, it spreads north and south. As the air spreads, it cools and sinks. At the same time, chilled air at the poles sinks toward Earth's surface. It pushes air at the surface outward. This air warms as it travels over the surface, so it rises. These upward and downward movements of air create winds. Winds transport heat from regions of rising warmer air to regions of sinking cooler air. Earth's rotation causes winds to blow generally from west to east over the temperate zones. Winds blow from east to west over the tropics and the poles.

Similar patterns of heating and cooling occur in the oceans. Winds push surface water, causing ocean currents. These currents transport enormous amounts of heat. Air that passes over warm currents picks up moisture and heat. Air that passes over cool currents is cooled. In this way, surface currents affect the weather and climate of nearby landmasses. Deep ocean currents are caused by cold water near the poles sinking and flowing along the ocean floor. This water rises in warmer regions through a process called upwelling.

Key Question What factors determine global climate?
Global climate is shaped by many factors, including solar energy trapped in the biosphere. Latitude and the transport of heat by winds and ocean currents also shape global climate.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The _____ is caused by gases in the atmosphere trapping heat, causing the Earth to warm.
2. A _____ develops when environmental conditions vary over small distances.

Critical Thinking

3. **Explain** How is climate different from weather?
4. **Quick Write** Research the average monthly high temperature (in °C) for Quito, Ecuador. Quito is a city on the equator. Plot the temperature data in a line graph. Describe the pattern shown.

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4.2 Niches and Community Interactions

The Niche

Different organisms live in different places. For example, one organism may live on a coral reef and another in the desert. What determines where an organism can live? Each species has a range of conditions under which it can grow and reproduce. These conditions help define where and how an organism lives.

Tolerance Every species has its own range of tolerance. Tolerance is the ability to survive and reproduce under a range of environmental conditions. When an environmental condition is outside of an organism's optimum range, the organism becomes stressed. It uses more energy to maintain homeostasis, and less for growth and reproduction. A species has an upper and lower limit of tolerance for every environmental factor. It cannot survive beyond those limits. A species' tolerance for environmental conditions helps determine its **habitat.** A habitat is the general place where an organism lives.

Defining the Niche Describing a species' habitat is important. But ecologists also study a species' ecological "job"—where and how it "makes a living." An organism's job is part of its **niche** (nitch). A niche describes what an organism does and how it interacts with the environment. A niche includes the way a species obtains **resources** to survive and reproduce. Resources include any necessity of life, such as water, nutrients, light, food, and space.

Key Question What is a niche?

A niche is the range of physical and biological conditions in which a species lives. It includes the way the species obtains what it needs to survive and reproduce.

Competition

Organisms often try to use a limited resource in the same place at the same time as other organisms. This process is called competition. Plant roots compete for water and nutrients in the soil. Animals compete for food, mates, and places to live and raise their young. Competition can occur among members of the same species (intraspecific competition) and between members of different species (interspecific competition).

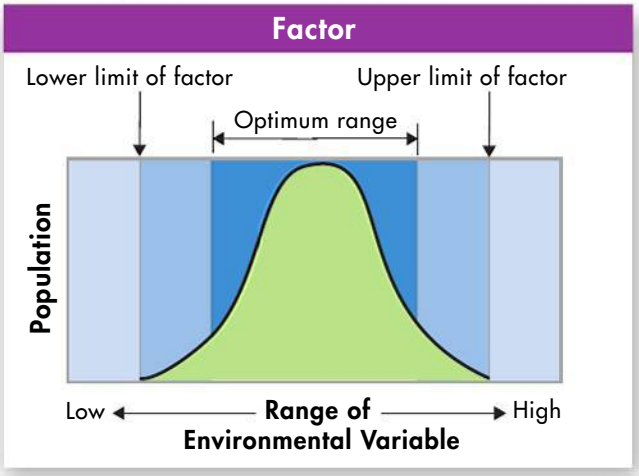
Key Questions

- ***What is a niche?***
- ***How does competition shape communities?***
- ***How do predation and herbivory shape communities?***
- ***What are the three primary ways that organisms depend on each other?***

BUILD Understanding

Concept Map Use the highlighted vocabulary words to create a concept map that organizes the information in this lesson.

In Your Workbook Go to your workbook for help completing a concept map. Complete the concept map in Lesson 4.2.



Tolerance A single environmental factor, such as sunlight or temperature, can affect population size. Organisms become more rare in zones of physiological stress (medium blue) and are absent from zones of intolerance (light blue).

BUILD Vocabulary

habitat an area where an organism lives, including the biotic and abiotic factors that affect it

niche the full range of physical and biological conditions in which an organism lives and the way in which the organism uses those conditions

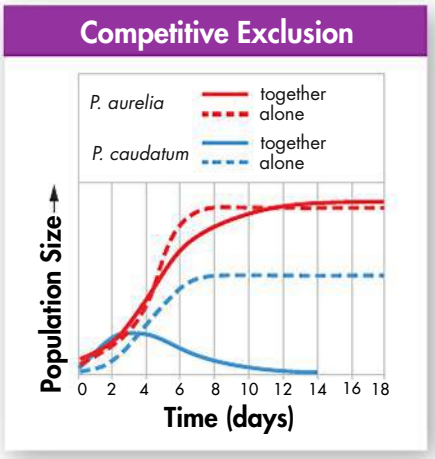
resource any necessity of life, such as water, nutrients, light, food, or space

predation an interaction in which one animal (the predator) captures and feeds on another animal (the prey)

herbivory an interaction in which one animal (the herbivore) feeds on producers (such as plants)

ROOT WORDS

The word *herb* means "a flowering plant without woody stems." When used as a root word, it usually refers to the leaves and flowers of plants. Animals that practice herbivory often prefer to eat leaves and flowers, but they may eat other plant parts as well.



Competitive Exclusion This graph shows what happens when two species of paramecia compete for the same resources. In separate cultures, the two species easily survive. But in the same culture, one species outcompetes the other. The losing species dies off.

The Competitive Exclusion Principle No two species can occupy the same niche in the same habitat at the same time. This fact is an ecological rule called the competitive exclusion principle. Direct competition between different species for a limited resource almost always produces a winner and a loser. The losing species dies out.

Dividing Resources Species usually divide similar resources instead of competing for them. For example, three species of warblers can all live in the same trees and feed on insects. One species feeds on high branches. Another feeds on low branches. The third feeds in the middle. In this way, each species has its own niche.

Key Question How does competition shape communities? **Competition causes species to divide resources. It helps determine the number and kinds of species in a community. It also determines the niche each species occupies.**

Predation, Herbivory, and Keystone Species

What happens if a group of animals eats all the available food in the area? They will no longer have anything to eat! That's why predator-prey and herbivore-plant interactions are very important.

Predator-Prey Relationships **Predation** (pree DAY shun) is an interaction in which one animal (predator) captures and feeds on another animal (prey). Predators can affect the size of prey populations in a community. For example, owls are predators that help regulate the populations of mice and other small mammals.

Herbivore-Plant Relationships **Herbivory** is an interaction in which one animal (herbivore) feeds on producers (such as plants). Herbivores can affect the size and distribution of plant populations in a community. For example, dense populations of white-tailed deer are eliminating some plants from many places in the United States.

Keystone Species Sometimes a population change in a single species can cause dramatic changes in its community. This species is called a keystone species. Pacific sea otters are a keystone species. These otters eat large numbers of sea urchins. Sea urchins are herbivores. Their favorite food is kelp, giant algae that grow in the ocean. A century ago, sea otters were nearly eliminated by hunting. Sea urchin numbers then skyrocketed, and the urchins devoured the kelp. Once the sea otters were protected as an endangered species, the otter population recovered. The sea urchin populations dropped, and the kelp thrived again.

Key Question How do predation and herbivory shape communities? **Predators can affect where prey populations can survive. Herbivores can help determine where populations of certain plants can survive.**

Symbioses

Any relationship in which two species live closely together is called **symbiosis** (sim by OH sis). Biologists recognize three main classes of symbiotic relationships in nature: mutualism, parasitism, and commensalism.

Mutualism The sea anemone uses its sting to capture prey and to protect itself from predators. But clownfish are immune to anemone stings. They hide from predators in the anemone's deadly tentacles. When an anemone is attacked, the clownfish fiercely chase away the much larger fish. This relationship is an example of **mutualism,** because both animals benefit from the relationship.

Parasitism Ticks live on the bodies of mammals, feeding on their blood and skin. This is an example of **parasitism** (PAR uh sit iz um). In this relationship, an organism lives inside or on another organism and harms it. The parasite obtains all or part of its nutrients from the host organism. Parasites weaken but usually do not kill their host.

Commensalism Small marine animals called barnacles often attach themselves to a whale's skin. The barnacles have no effect on the whale. They benefit from the constant movement of water and food particles past the swimming whale. This is an example of **commensalism** (kuh MEN sul iz um). In this relationship, one organism benefits and the other is neither helped nor harmed.

Key Question What are the three primary ways that organisms depend on each other? **The three main classes of symbiotic relationships are mutualism, parasitism, and commensalism.**

BUILD Vocabulary

symbiosis
a relationship in which two species live closely together

mutualism
the symbiotic relationship in which both species benefit from the relationship

parasitism
the symbiotic relationship in which one organism lives on or inside another organism and harms it

commensalism
the symbiotic relationship in which one organisms benefits and the other is neither helped nor harmed

ROOT WORDS

The word *commensal* means "eating together at the same table." So organisms that practice commensalism could be said to be dinner companions.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A _____ is something that is essential for an organism's life.

2. A relationship in which the interaction between organisms is helpful to both is called _____.

Critical Thinking

3. Compare and Contrast What is the difference between a predator and a parasite?

4. Write to Learn Answer the first clue of the mystery.

MYSTERY CLUE

One of the favorite prey species of the wolves in Yellowstone is elk. How do you think this relationship could affect the ability of certain *plants* to grow in Yellowstone? (Hint: See p. 86.)

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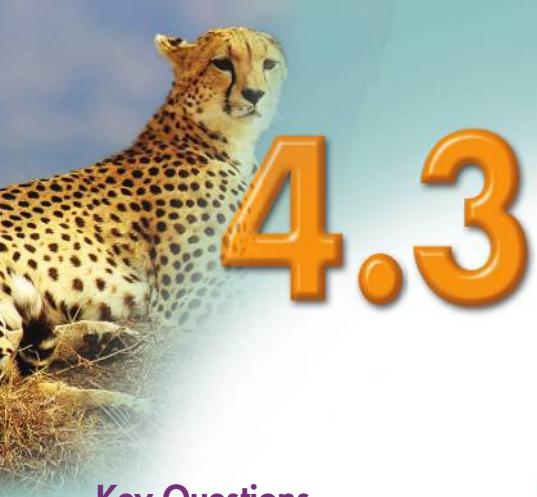


4.3 Succession

Key Questions

- ***How do communities change over time?***
- ***Do ecosystems return to "normal" following a disturbance?***

BUILD Understanding

Compare/Contrast Table As you read, create a table comparing primary and secondary succession.

In Your Workbook Go to your workbook to learn more about creating a compare/contrast table.

Primary and Secondary Succession

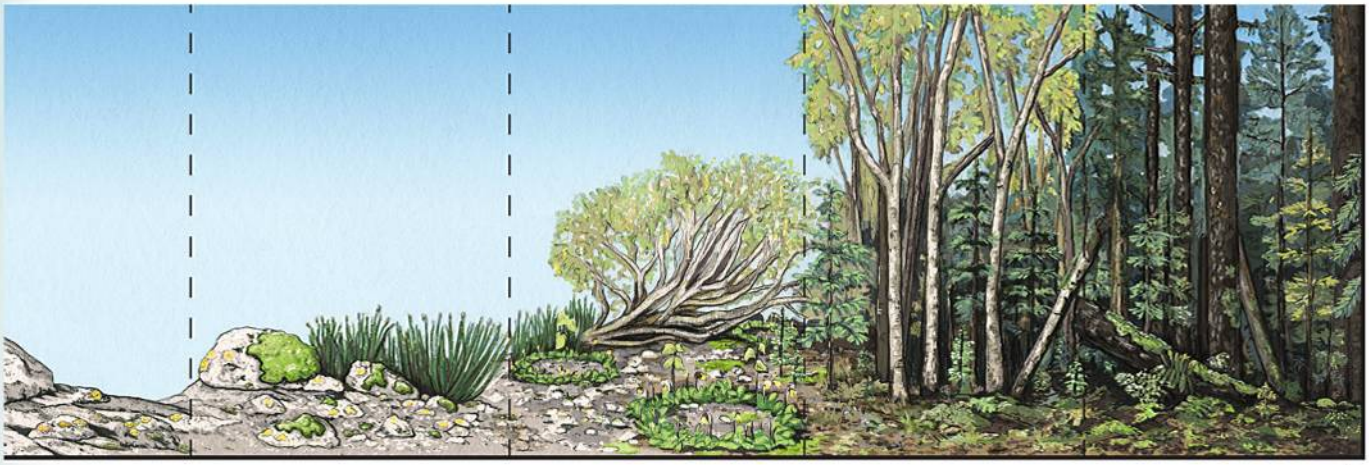
In 1883, an eruption blew the volcanic island of Krakatau in the Indian Ocean to pieces. A tiny barren island remained. By 1929, a forest with over 300 species covered the island. Today it is a mature rain forest. Krakatau is an example of **ecological succession.** Succession is a series of more-or-less predictable changes that occur in a community over time. As succession proceeds, the number of different species present typically increases.

Primary Succession Volcanic explosions and retreating glaciers can create new land or sterilize existing areas. Both events leave only exposed bare rock—no soil or plant life. Succession that begins in an area that has no existing community is called **primary succession.**

The first species to colonize barren areas are called **pioneer species.** One pioneer that grows on bare rock is lichen. Lichen is an example of mutualism between a fungus and an alga. Lichens fix atmospheric nitrogen into useful forms for other organisms. Over time, they break down rock and add organic material to form soil. Some grasses are also pioneer species.

Secondary Succession Existing communities are not always completely destroyed by disturbances. In these cases, **secondary succession** occurs. Secondary succession proceeds faster than primary succession. The soil remains, so new and surviving vegetation regrows rapidly.

Primary Succession Primary succession occurs on newly exposed surfaces. In Glacier Bay, Alaska, a retreating glacier exposed barren rock. Over the course of more than 100 years, a series of changes has led to the hemlock and spruce forest currently found in the area. Changes in this community will continue for centuries.



Secondary succession often follows a wildfire, hurricane, or other natural disturbance. To us, these events are disasters, but many species are adapted to them. Forest fires kill some trees, but spare others—and may stimulate their seeds to germinate. Secondary succession can also follow human activities like logging and farming.

Why Succession Occurs Every organism changes the environment it lives in. In one model of succession, as one species alters its environment, other species find it easier to compete for resources and survive. Lichens add organic matter and form soil. Then mosses and other plants are able to colonize and grow. Organic matter accumulates and soon other species move in. Tree branches produce shade and cooler temperatures nearer the ground. Over time, more and more species can find suitable niches and survive.

Key Question How do communities change over time? **Ecosystems change over time, especially after disturbances. As some species die out, new species move in.**

Climax Communities

Ecologists used to think that succession in a given area always proceeded through the same stages. The end result was a specific and stable community called a climax community. But recent studies have shown that succession doesn't always follow the same path. Climax communities are not always uniform and stable.

Succession After Natural Disturbances Natural disturbances are common in many communities. Healthy coral reefs and tropical rain forests recover from storms. Healthy temperate forests and grasslands recover from wildfires. Sometimes succession in a healthy ecosystem reproduces the original climax community after a natural disturbance. But multiple disturbances take place at different times in some ecosystems. This causes climax communities that are not uniform. They look like patchwork quilts because different areas are in varying stages of succession. Some climax communities are disturbed so often that they can't really be called stable.

BUILD Vocabulary

ecological succession
a series of gradual changes that occur in a community following a disturbance

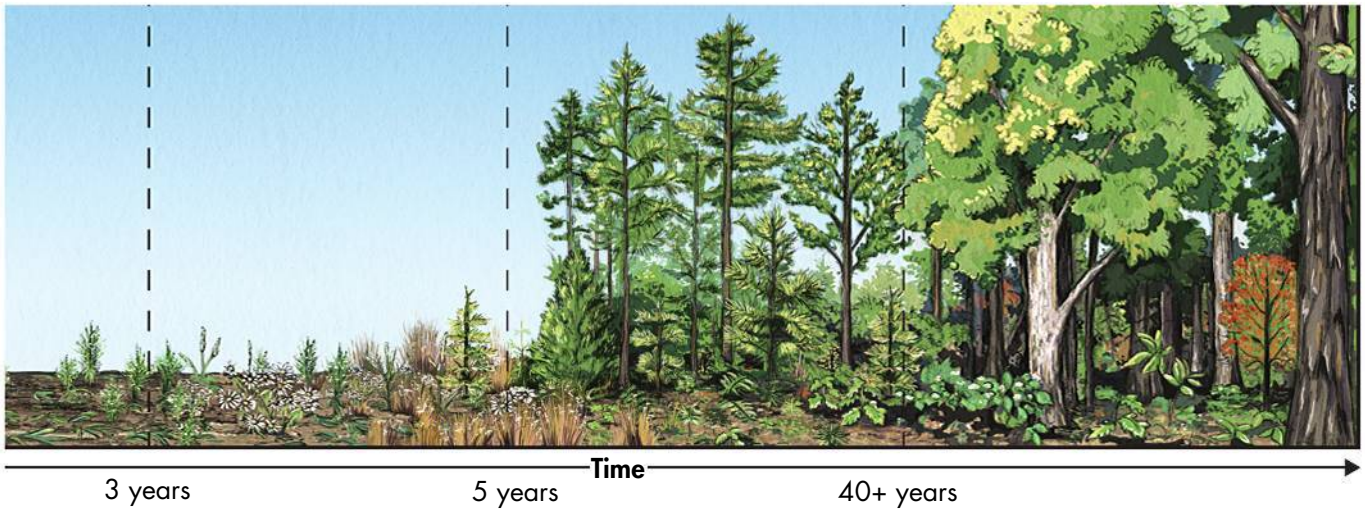
primary succession
succession that occurs in an area in which no trace of a previous community is present

pioneer species
the first species to populate an area during succession

secondary succession
a type of succession that occurs in an area that was only partially destroyed by disturbances

WORD ORIGINS

The origin of the word *succession* is the Latin word *succedere*, meaning "to come after." Ecological succession involves changes that occur one after the other as species move into and out of a community.



Secondary Succession Secondary succession occurs in disturbed areas where parts of previous ecosystems still remain. This series shows changes taking place in abandoned fields in the Carolinas. Over the last century, the fields have passed through several stages and matured into oak forests. Changes will continue for years to come.

Studying Succession These Forest Service rangers are surveying plants and animals that have returned to Mount Saint Helens. The volcano erupted in 1980, leaving only barren land for miles.

Succession After Human-Caused Disturbances In North America, land cleared for farming and then abandoned often passes through succession. In some cases, the original climax community is restored. But restoration does not always happen. Ecosystems may or may not recover from extensive human-caused disturbances. For example, when tropical rain-forest land is cleared and farmed, the microclimate and soil often change. These changes prevent regrowth of the original community.

Studying Patterns of Succession Ecologists study succession by comparing different cases and looking for similarities and differences. For example, researchers swarmed over Mount Saint Helens as soon as it was safe. These researchers might also have studied Krakatau. In both places, primary succession proceeded through predictable stages. Seeds, spores, or adult stages of the first plants and animals traveled over long distances. Hardy pioneer species helped stabilize loose volcanic debris, which allowed later plant species to take root.

Studies of Krakatau and Mount Saint Helens prove that early stages of primary succession are slow. Opportunity can play a large role in determining which species colonize at different times.

Key Question Do ecosystems return to "normal" following a disturbance?

In healthy ecosystems, secondary succession often reproduces the original climax community after a natural disturbance. But ecosystems may or may not recover from widespread disturbances caused by humans.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The first species to colonize an area during ecological succession is called a _____.
2. Succession that begins after a wildfire is usually _____, because soil is already present.
3. Succession that begins after a volcanic eruption is usually _____, because it starts with bare rock.

Critical Thinking

4. **Explain** What is a climax community?
5. **Relate Cause and Effect** What kinds of conditions might prevent a community from returning to its predisturbance state?
6. **Quick Write** Look at the photo below. Write a paragraph explaining what sort of succession this is, and why.

BIOLOGY.com Search Lesson 4.3 GO • Lesson Assessment

4.4 Biomes

The Major Biomes

Why are the characteristics of biological communities different from one place to another? You learned that latitude affects global climate. So does the heat transported by winds. But regions with similar latitudes and prevailing winds may have different climates and biological communities. Why? Because other factors can also influence climate. These factors include an area's nearness to an ocean or a mountain range.

Regional Climates Oregon, for example, borders the Pacific Ocean, which has cold currents flowing from north to south. Cold currents make the region cooler in summer than other places at the same latitude. Similarly, prevailing winds traveling west to east push moist air upward against the Cascade Mountains. The air expands and cools, causing the moisture to condense and form clouds. The clouds then drop rain or snow on western Oregon. But the air descends on the eastern side of the mountains, becoming warmer and drier. So, much less rain falls in east Oregon. West and east Oregon have very different regional climates. Therefore, the areas also have different plant and animal communities.

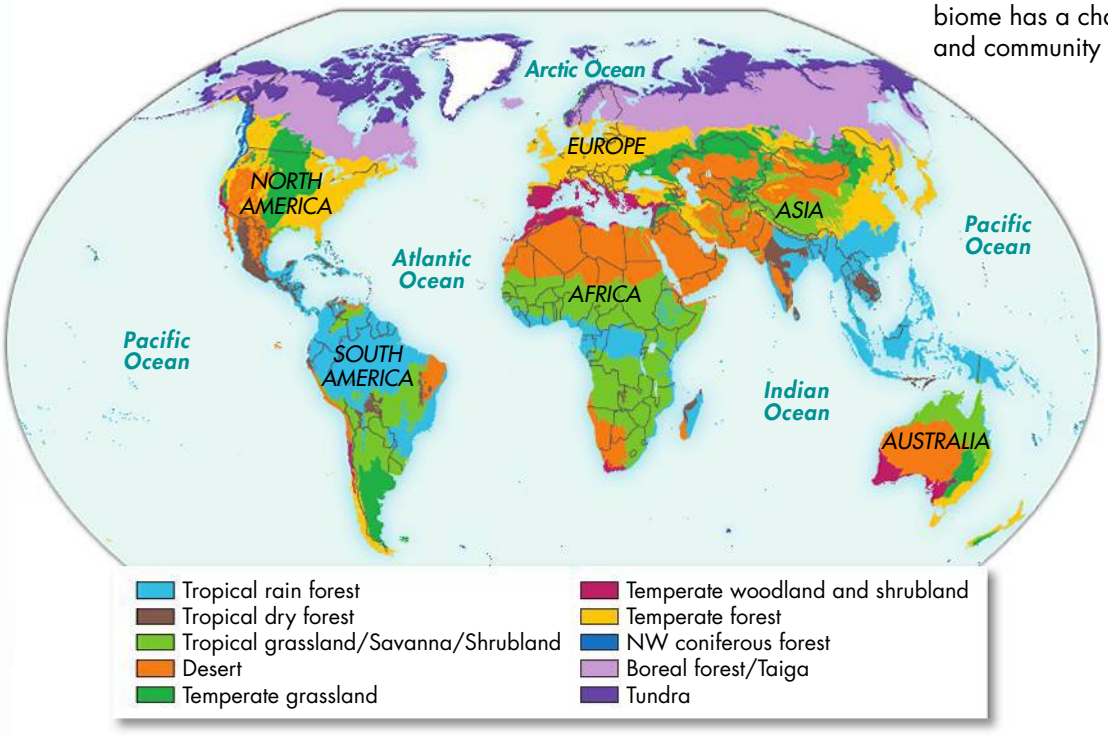
Key Questions

- ***What abiotic and biotic factors characterize biomes?***
- ***What areas are not easily classified into a major biome?***

BUILD Understanding

Preview Visuals Before you read, preview the biome map. Study the names of the biomes carefully.

In Your Workbook As you read, examine the photographs of the biomes. Complete the table in Lesson 4.4 by filling in the missing information.

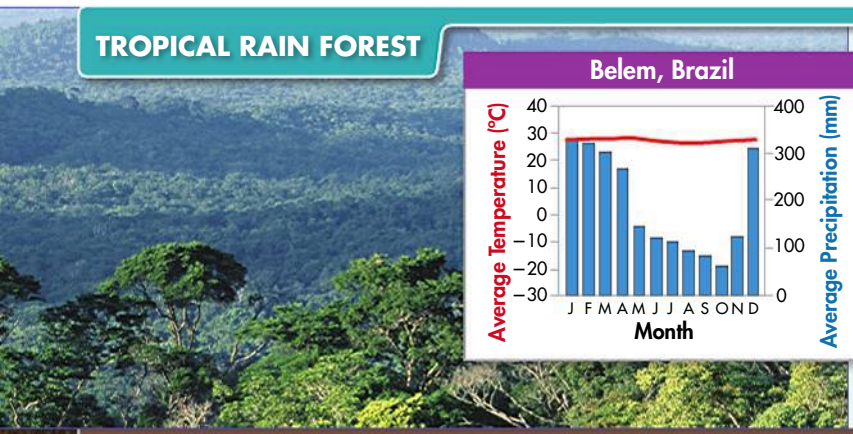


Biomes This map shows the locations of the world's major biomes. Each biome has a characteristic climate and community of organisms.

Defining Biomes Earth's terrestrial ecosystems are classified into ten groups of regional climate communities called biomes. A biome is described by its abiotic factors, such as climate and soil type. Each biome has a seasonal pattern of temperature and precipitation. A biome is also described by its biotic factors, such as plant and animal life. Organisms in each biome have adaptations so they can live and reproduce in the environment. Plant and animal communities often vary even if they are in the same biome. Variations can be caused by differences in exposure, elevation, or local soil conditions. Human activity or community interactions may also change local conditions.

Key Question What abiotic and biotic factors characterize biomes? **Biomes are described in terms of abiotic factors like climate and soil type. They are also described by biotic factors like plant and animal life.**

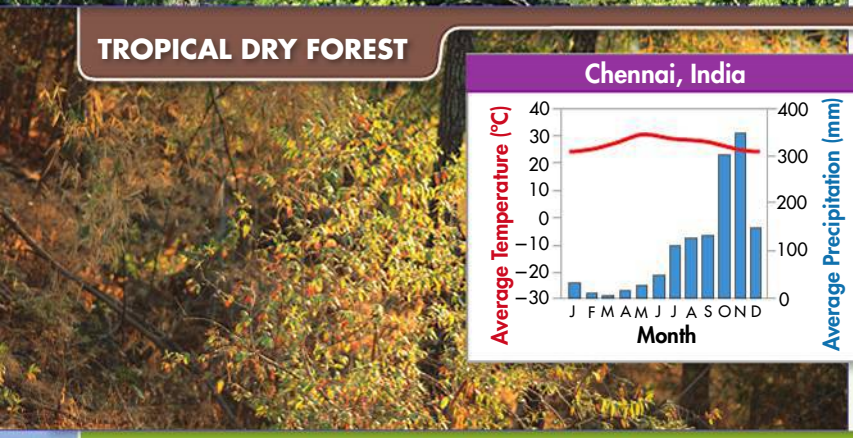
TROPICAL RAIN FOREST



Tropical rain forests have more species than all the other biomes combined. They get at least 2 meters of rain a year! Tall trees form a dense, leafy covering called a **canopy.** The canopy shades a layer of shorter trees and vines called the **understory.**

- **Abiotic factors** hot and wet year-round; thin, nutrient-poor soils subject to erosion
- **Biotic factors–Plant life:** Understory plants use large leaves to compete for limited light. **Animal life:** Animals are active all year. Many use camouflage to hide from predators.

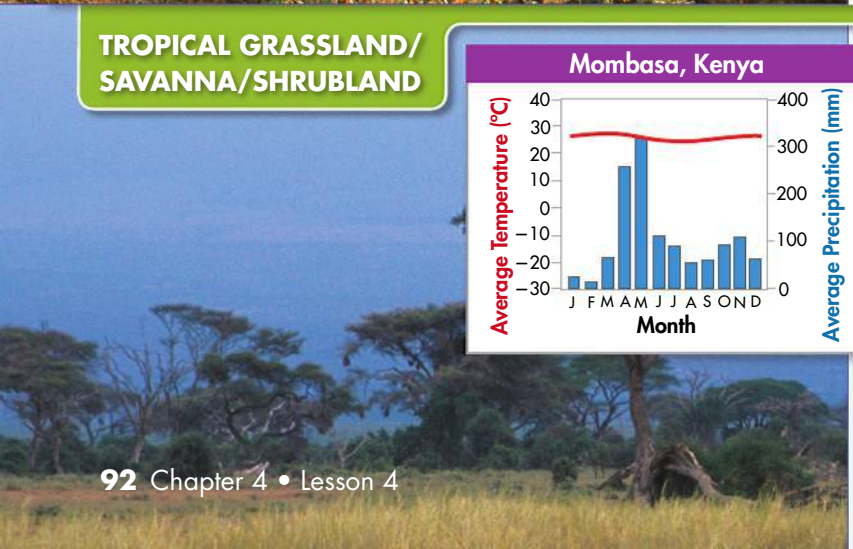
TROPICAL DRY FOREST



Tropical dry forests grow in areas where rainy seasons alternate with dry seasons.

- **Abiotic factors** warm year-round; usually, a period of rain is followed by a long period of drought
- **Biotic factors–Plant life:** Some plants lose leaves to survive the dry season. A plant with this adaptation is *deciduous*. **Animal life:** During dry season, many animals reduce their need for water by entering long periods of inactivity. This period of inactivity is called estivation, and it is similar to hibernation.

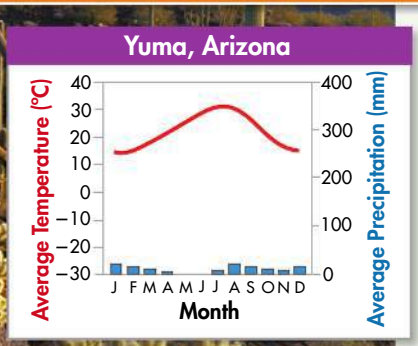
TROPICAL GRASSLAND/ SAVANNA/SHRUBLAND



This biome receives more seasonal rainfall than deserts but less than tropical dry forests. It is mostly grass, with isolated trees and small groves of trees and shrubs.

- **Abiotic factors** warm; seasonal rainfall; compact soils; frequent fires set by lightning
- **Biotic factors–Plant life:** Plant adaptations include waxy leaf coverings and seasonal leaf loss. **Animal life:** Many animals migrate during the dry season to find water. Some smaller animals burrow and remain inactive during the dry season.

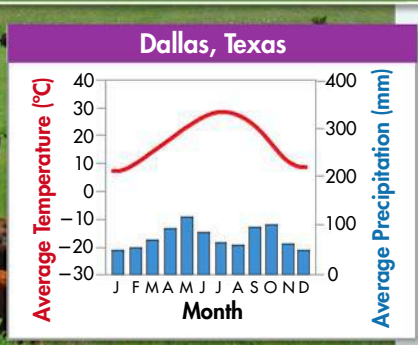
DESERT



Deserts have less than 25 centimeters of precipitation annually. Deserts vary greatly, depending on elevation and latitude. Many deserts undergo extreme daily temperature changes, alternating between hot and cold.

- **Abiotic factors** low precipitation; variable temperatures
- **Biotic factors–Plant life:** Many plants store water in their tissues. They also minimize leaf surface area to cut down on water loss. **Animal life:** Many desert animals get water from the food they eat. Many are active at night to avoid the hottest parts of the day.

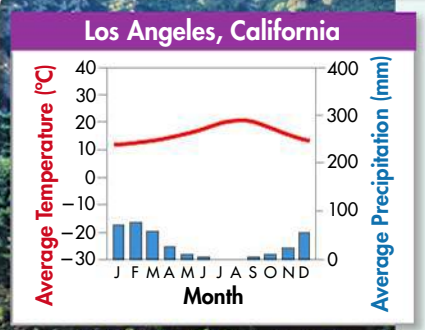
TEMPERATE GRASSLAND



Plant communities are mostly grasses, which have been maintained by periodic fires and heavy grazing. Their soils are fertile and ideal for growing crops. For this reason, most have been converted for agriculture.

- **Abiotic factors** warm to hot summers; cold winters; moderate seasonal precipitation; occasional fires
- **Biotic factors–Plant life:** Grassland plants are resistant to grazing and fire. **Animal life:** Predation is a threat for smaller animals because of the open environment. Camouflage and burrowing are common adaptations.

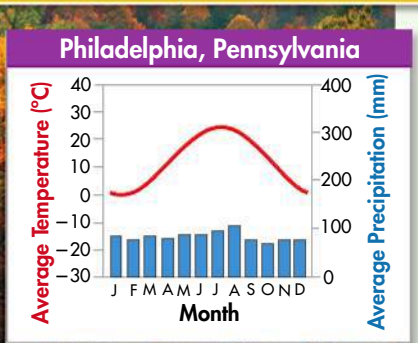
TEMPERATE WOODLAND AND SHRUBLAND



Open woodlands have large areas of grasses and wildflowers mixed with oak and other trees. Fire is a constant threat because of dense, low, oily plants.

- **Abiotic factors** hot dry summers; cool moist winters; thin, nutrient-poor soils; periodic fires
- **Biotic factors–Plant life:** Plants in this biome have adapted to drought. They have tough waxy leaves that resist water loss. **Animal life:** Animals tend to be browsers that eat varied diets of grasses, leaves, shrubs, and other vegetation.

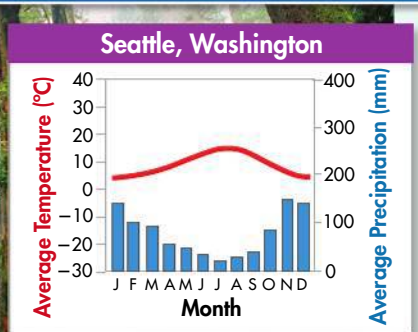
TEMPERATE FOREST



Temperate forests are mostly made up of deciduous and evergreen coniferous (koh NIF ur us) trees. Soils are fertile, and are often rich in **humus.** Humus is a material formed from decaying leaves and other organic matter.

- **Abiotic factors** cold to moderate winters; warm summers; year-round precipitation; fertile soils
- **Biotic factors–Plant life:** Deciduous trees drop their leaves in autumn and go dormant in winter. **Animal life:** Animals must cope with changing weather. Bare trees leave animals exposed in winter.

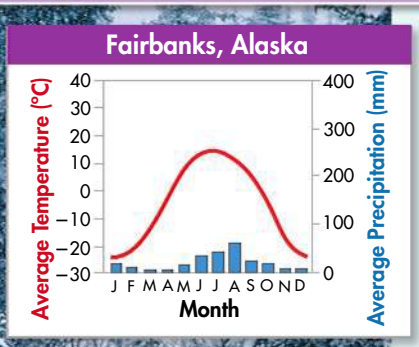
NORTHWESTERN CONIFEROUS FOREST



The forest has a variety of conifers, flowering trees, and shrubs. Moss often covers tree trunks and the forest floor. This biome is sometimes called a "temperate rain forest" because of its lush vegetation.

- **Abiotic factors** mild temperatures; abundant precipitation in fall, winter, and spring; cool dry summers
- **Biotic factors–Plant life:** This biome is less diverse than a tropical rain forest. Ample water and nutrients support lush, dense plant growth. Trees here are among the world's tallest. **Animal life:** Camouflage helps insects and ground-dwelling mammals avoid predation.

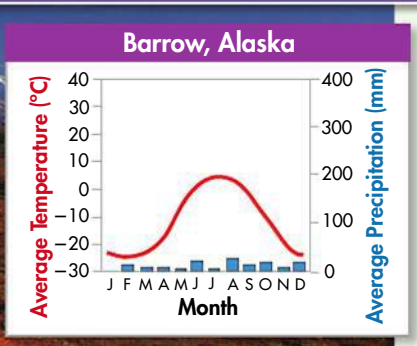
BOREAL FOREST



Boreal forests, or **taiga** (TY guh), are dense forests of coniferous evergreens. They are found along the northern edge of the temperate zone.

- **Abiotic factors** long cold winters; short mild summers; moderate precipitation; high humidity; acidic, nutrient-poor soils
- **Biotic factors–Plant life:** Conifers are well suited to this biome. Their shape sheds snow. Wax-covered, needlelike leaves reduce water loss. **Animal life:** To stay warm most animals have small limbs and ears, and fat or downy feathers for insulation.

TUNDRA



The tundra is identified by **permafrost,** a layer of permanently frozen subsoil. In summer, the ground thaws to a depth of a few centimeters and becomes soggy. In winter, the top layer of soil freezes again. This cycle of thawing and freezing rips and crushes plant roots. Cold temperatures, high winds, a short growing season, and humus-poor soils also limit plant height.

- **Abiotic factors** strong winds; low precipitation; short and soggy summers; long, cold, dark winters; permafrost
- **Biotic factors–Plant life:** Mosses and other plants are low-growing to avoid damage from frequent strong winds. **Animal life:** Many animals migrate to avoid long harsh winters. Animals that live in the tundra year-round have adaptations such as natural antifreeze to limit heat loss.

BUILD Vocabulary

canopy a dense covering formed by the leafy tops of tall rain forest trees

understory the layer in a rain forest found underneath the canopy formed by shorter trees and vines

humus material formed from decaying leaves and other organic matter

taiga a biome with long cold winters and a few months of warm weather; dominated by coniferous evergreens; also called boreal forest

permafrost a layer of permanently frozen subsoil found in the tundra

WORD ORIGINS

The word *taiga* is Russian for "dense evergreen forest." Gradually, it became the name of the biome where these Russian forests are found.

Other Land Areas

Some land areas are not easily defined in terms of a typical community of plants and animals. For this reason, mountain ranges and polar ice caps are not usually classified into biomes.

Mountain Ranges Mountain ranges exist on all continents and in many biomes. Conditions such as temperature and precipitation vary with elevation. Exposure to wind increases and soil types and organisms change as you move up from the valley to the mountain summit. For example, the base of the Rocky Mountains in Colorado is grassland. As you climb upward, you enter pine woodland, then a forest of spruce and other conifers. Aspen and willow trees grow in thickets along protected valley streambeds. Near the top, winds are strong and batter open fields of wildflowers. The stunted vegetation resembles tundra. Glaciers are often found at the peaks.

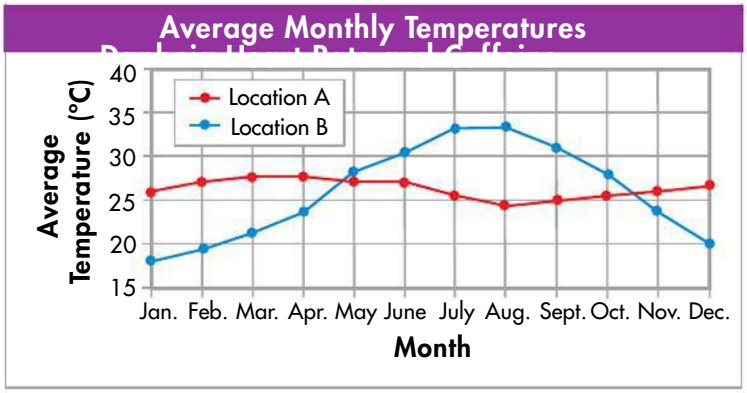
Polar Ice Caps Polar regions border the tundra and are cold year-round. There are few plants, but some algae grow on snow and ice. Animal life includes marine mammals, insects, and mites. In the north, the Arctic Ocean is covered with sea ice and inhabited by polar bears. In the south, the continent of Antarctica is inhabited by many species of penguins. The ice there is nearly 5 kilometers thick in places.

Key Question What areas are not easily classified into a major biome? **Mountain ranges and polar ice caps are not usually classified into biomes. They are not easily defined in terms of a typical community of plants and animals.**

INQUIRY into Scientific Thinking

Which Biome?

An ecologist collected climate data from two locations. The graph shows the monthly average temperatures in the two locations. The total yearly precipitation in Location A is 273 cm. In Location B, the total yearly precipitation is 11 cm.



Analyze and Conclude

1. **Interpret Graphs** What is the variable plotted on the horizontal (X) axis? What is the variable plotted on the vertical (Y) axis?

2. **Interpret Graphs** How would you describe the temperature over the course of the year in the two locations?

3. **Draw Conclusions** In which biome would you expect to find each location, given the precipitation and temperature data? Explain your answer.

In Your Workbook Go to your workbook for more help wth this activity.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The _____ in a tropical rain forest is made up of shorter trees and vines that live in the shade of the tallest trees.

2. The soils in temperate forests are often rich in _____, which is made up of decaying leaves and organic matter.

3. Dense coniferous forests and animals with small ears and limbs are characteristics of the _____ biome.

Critical Thinking

4. **Explain** How are biomes classified?

5. **Write to Learn** Answer the second clue of the mystery. Be sure to include the effect of microclimates in your answer.

MYSTERY CLUE

Yellowstone has high mountain slopes and valleys with streams. Moose and elk prefer to graze in the valleys instead of on the mountain slopes. How do you think their preference might affect Yellowstone's plant communities? (Hint: See p. 94.)

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4.5 Aquatic Ecosystems

Key Questions

- ***What factors affect life in aquatic ecosystems?***
- ***What are the major categories of freshwater ecosystems?***
- ***Why are estuaries so important?***
- ***How do ecologists usually classify marine ecosystems?***

BUILD Understanding

Compare/Contrast Table As you read, note the similarities and differences between freshwater and marine ecosystems in a compare/contrast table.

In Your Workbook Go to Lesson 4.5 in your workbook to learn more about making a compare/contrast table.

Conditions Underwater

We call our planet "Earth." But almost three fourths of Earth's surface is covered with water. What is life like underwater?

Underwater organisms are affected by a variety of environmental factors. These factors include the water depth, temperature, flow, and amount of dissolved nutrients. Runoff from land can affect some factors, so distance from shore also shapes marine communities.

Water Depth Sunlight only penetrates a short distance through water. This region is called the photic zone. It ranges from 200 meters deep (tropical seas) to less than a few meters (swamps). Photosynthetic algae called phytoplankton live here. They are eaten by tiny free-floating animals called zooplankton. Below the photic zone is the dark aphotic zone, where photosynthesis cannot occur.

Many aquatic organisms live on, or in, rocks and sediments on the bottoms of lakes, streams, and oceans. These organisms are called the **benthos,** and their habitat is the benthic zone. In shallow waters the benthos are in the photic zone. Algae and rooted aquatic plants grow here. In the aphotic zone, chemosynthetic autotrophs are the only primary producers.

Temperature and Currents Aquatic habitats are warmer near the equator and colder near the poles. Temperature in aquatic habitats also varies with depth. The deepest parts of lakes and oceans are often colder than surface waters. Currents can dramatically affect water temperature, too. They can carry water that is noticeably warmer or cooler than normal into a given area.

The Photic Zone Sunlight penetrates only a limited distance into aquatic ecosystems. Whatever the depth, the photic zone is the only area in which photosynthesis can occur.

Nutrient Availability Aquatic organisms need certain substances to live, including oxygen, nitrogen, potassium, and phosphorus. The type and availability of these dissolved substances varies within and between bodies of water. This difference greatly affects the types of organisms that can survive there.

Key Question What factors affect life in aquatic ecosystems? **Aquatic organisms are affected primarily by the water's depth, temperature, flow, and amount of dissolved nutrients.**

Freshwater Ecosystems

Only 3 percent of Earth's surface water is fresh water. Freshwater ecosystems can be divided into three main categories: rivers and streams, lakes and ponds, and freshwater wetlands.

Rivers and Streams Rivers, streams, creeks, and brooks often originate from underground water sources in mountains or hills. Water has little plant life here. Downstream, sediments build up and plants establish themselves. Farther downstream, water may wander slowly through flat areas. Animals in many rivers and streams depend for food on plants and other animals that live along the banks.

Lakes and Ponds Food webs in lakes and ponds often are based on plankton and attached algae and plants. **Plankton** is a general term that includes both phytoplankton and zooplankton. Water typically flows in and out of lakes and ponds. It also circulates between the surface and the benthos during at least some seasons. This movement distributes heat, oxygen, and nutrients.

Freshwater Wetlands A **wetland** is an ecosystem in which water either covers the soil or is present at or near the surface for at least part of the year. Water may flow through wetlands or remain still. Wetlands are often nutrient-rich and highly productive, and they serve as breeding grounds for many organisms. Freshwater wetlands purify water by filtering pollutants. Wetlands help to prevent flooding by absorbing and slowly releasing water. Three main types of freshwater wetlands are freshwater bogs, freshwater marshes, and freshwater swamps. Saltwater wetlands are called estuaries.

Key Question What are the major categories of freshwater ecosystems?

Freshwater ecosystems can be divided into three main categories: rivers and streams, lakes and ponds, and freshwater wetlands.

BUILD Vocabulary

benthos
organisms that live attached to or near the bottom of lakes, streams, or oceans

plankton
typically small organisms that drift in, and may swim through, aquatic environments; includes both phytoplankton and zooplankton

wetland
an ecosystem in which water either covers the soil or is present at or near the surface for at least part of the year

estuary
a kind of wetland formed where a river meets the ocean

WORD ORIGINS

The word *benthos* is Greek for "depth of the sea." Many of the most unusual benthic organisms live in the deepest parts of the open ocean.

Freshwater Ecosystems Freshwater ecosystems include streams, lakes, and freshwater wetlands (bogs, marshes, and swamps).

Estuaries Salt marshes and mangrove swamps are estuaries. These are areas where fresh water from rivers meets salt water.

Estuaries

Estuaries (ES tyoo ehr ee) are wetlands that form where a river meets the sea. They contain a mixture of fresh water and salt water and are affected by ocean tides. Many are shallow, so enough sunlight reaches the benthos to power photosynthesis. Estuaries support an astonishing amount of biomass. They serve as breeding and nursery grounds for many important fish and shellfish species.

Salt marshes are temperate estuaries. Salt marshes have salt-tolerant grasses above the low-tide line and seagrasses below water. The Chesapeake Bay in Maryland is a salt marsh. Mangrove swamps, such as the Everglades, are tropical estuaries. They are identified by several species of salt-tolerant trees, called mangroves.

Key Question Why are estuaries so important?
Estuaries serve as breeding and nursery grounds for many ecologically and commercially important fish and shellfish species.

Marine Ecosystems

Marine ecosystems usually occupy specific zones within the ocean, based on depth and distance from shore.

Intertidal Zone Organisms in the intertidal zones are subjected to regular and extreme changes in temperature. At high tide, they are submerged in seawater and often battered by waves and currents. At low tide, they are exposed to air and sunlight.

Coastal Ocean The coastal ocean extends from the low-tide mark to the outer edge of the continental shelf. The continental shelf is the relatively shallow border that surrounds the continents. Water here is brightly lit and often supplied with nutrients by freshwater runoff from land. This makes coastal oceans highly productive. Kelp forests and coral reefs are two exceptionally important coastal communities.

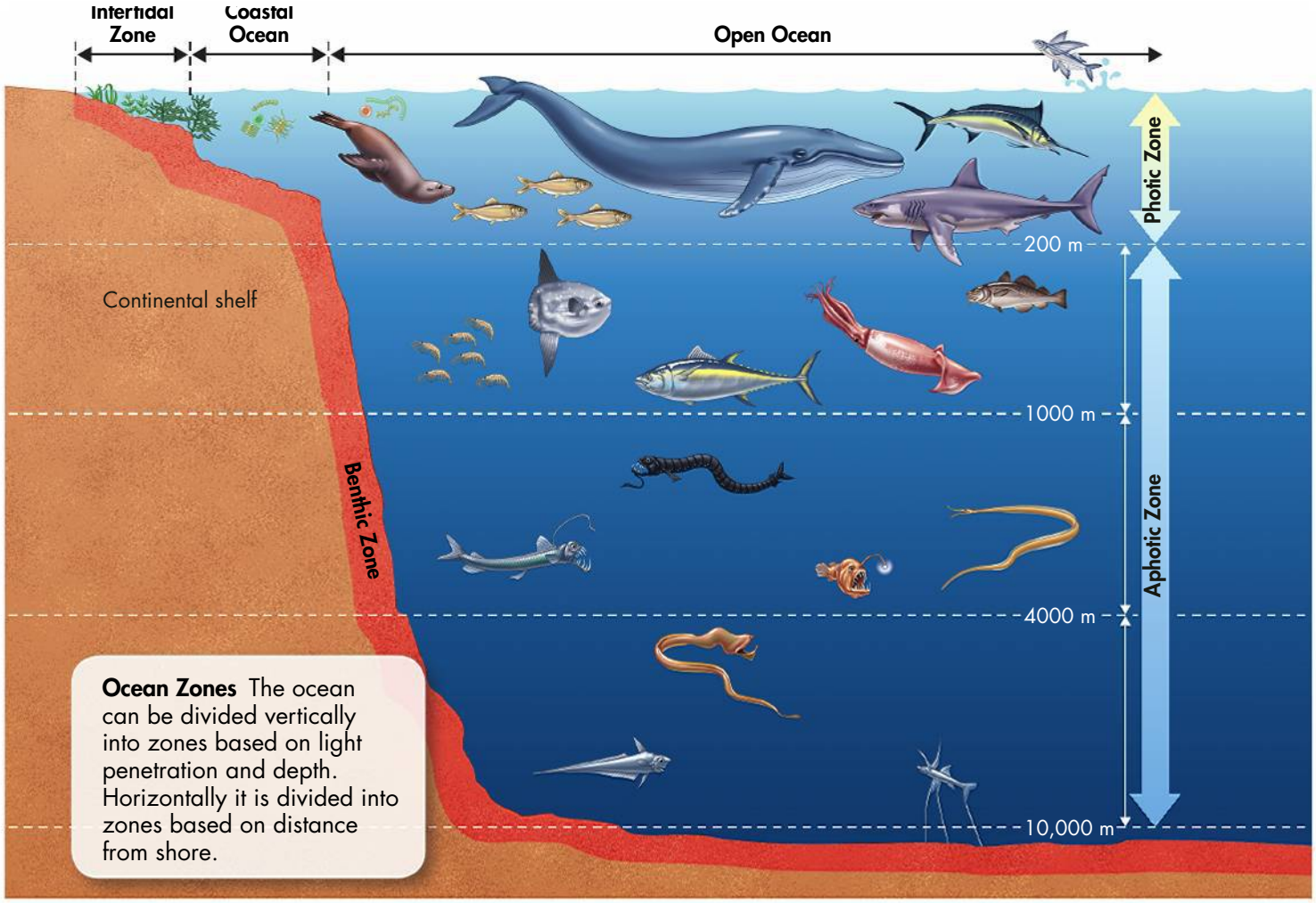
Open Ocean The open ocean begins at the edge of the continental shelf. It is divided into the photic zone and the aphotic zone.

▶ ***The Open Ocean Photic Zone*** The open ocean typically has low nutrient levels and supports only the smallest species of phytoplankton. Still, because of its enormous area, most photosynthesis on Earth occurs in the sunlit top 100 meters of the open ocean.

▶ ***The Open Ocean Aphotic Zone*** The permanently dark aphotic zone includes the deepest parts of the ocean. Its food webs are usually based on organisms that fall from the photic zone. Some food webs here are based on chemosynthetic primary producers.

Key Question How do ecologists usually classify marine ecosystems? **Ecologists divide the ocean into zones based on depth and distance from shore.**

Creature From the Deep This silver hatchetfish lives in the aphotic zone of the Gulf of Mexico.



Ocean Zones The ocean can be divided vertically into zones based on light penetration and depth. Horizontally it is divided into zones based on distance from shore.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. _____ is the group of organisms that is often at the base of food webs in open-water aquatic ecosystems.
2. Aquatic organisms that grow in the sediments at the bottom of a pond or lake are called the _____.

Critical Thinking

3. **Explain** What are the primary abiotic factors that affect life underwater?
4. **Apply Concepts** Why is it important to protect estuaries?
5. **Write to Learn** Answer the third clue to the mystery. Where do you think the streams in Yellowstone most likely originate?

MYSTERY CLUE

How might the presence or absence of plants along stream banks affect life in Yellowstone's streams? (Hint: See p. 97.)

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Pre-Lab: Abiotic Factors and Plant Selection

Problem How can you decide which plants will thrive in a garden?

Materials plant hardiness zone map, plant catalogs, graph paper, tape measure

Lab Manual Chapter 4 Lab

Skills Focus Classify, Analyze Data, Use Models

Connect to the Big idea Why are white birch trees abundant in Minnesota, but not in the Florida Keys? Why do coconut palms grow in the Florida Keys, but not in Minnesota? Simply put, white birch trees could not tolerate the hot summers in the Keys and coconut palms could not tolerate the cold winters in Minnesota. A plant's habitat is determined by its range of tolerance for temperature and other abiotic factors. In other words, abiotic factors limit where a given plant can live.

In this lab, you will plan a garden for a specific location. You will select plants for the garden that can tolerate the abiotic factors in this location.

Background Questions

a. **Review** What is an abiotic factor? List three examples other than temperature.

b. **Review** What kinds of resources do plants need?

c. **Relate Cause and Effect** Give an example of an adaptation that helps a plant survive in a biome with low precipitation.

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Predict** How will knowing the plant hardiness zone for your area help you plan a garden?

2. **Relate Cause and Effect** What is the relationship between the last frost and the length of the growing season?

3. **Form a Hypothesis** A plant species grows well in one location in a small garden but does not grow as well in another location. Suggest one possible reason for this difference.

BIOLOGY.com Search Chapter 4 GO

Visit Chapter 4 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Join the Untamed Science crew as they explore succession after a volcanic eruption on Hawaii.

Visual Analogy Compare Earth's atmosphere to a greenhouse.

Art in Motion View a short animation that brings succession to life.

Art Review Review your understanding of ocean zones with this drag-and-drop activity.

4 CHAPTER Summary

4.1 Climate

- A region's climate is defined by year-after-year patterns and averages of temperature and precipitation.
- Global climate is shaped by many factors, including the amount of solar energy that is trapped in the biosphere. The transport of heat by winds and ocean currents also shapes global climate.

climate (p. 82)
microclimate (p. 82)
greenhouse effect (p. 83)

4.2 Niches and Community Interactions

- A niche is the range of physical and biological conditions in which a species lives. It includes the way that a species obtains what it needs to survive and reproduce.
- Competition causes species to divide resources. It helps determine the number and kinds of species in a community. It also helps to shape the niche each species occupies.
- Predators and herbivores can affect the size of other populations in a community. Predators can affect where prey populations can survive. Herbivores can help determine where populations of certain plants can survive and grow.
- The three main classes of symbiotic relationships in nature are mutualism, parasitism, and commensalism.

habitat (p. 85)
niche (p. 85)
resource (p. 85)
predation (p. 86)
herbivory (p. 86)
symbiosis (p. 87)
mutualism (p. 87)
parasitism (p. 87)
commensalism (p. 87)

4.3 Succession

- Ecosystems change over time, especially after disturbances. As some species die out, new species move in.
- In healthy ecosystems, secondary succession often reproduces the original climax community after a natural disturbance. But ecosystems may or may not recover from widespread disturbances caused by humans.

ecological succession (p. 88)
primary succession (p. 88)
pioneer species (p. 88)
secondary succession (p. 88)

4.4 Biomes

- Biomes are described in terms of abiotic factors like climate and soil type. They are also described by biotic factors like plant and animal life.
- Mountain ranges and polar ice caps are not usually classified into biomes. They are not easily defined in terms of a typical community of plants and animals.

canopy (p. 92)
understory (p. 92)
humus (p. 93)
taiga (p. 94)
permafrost (p. 94)

4.5 Aquatic Ecosystems

- Aquatic organisms are affected primarily by the water's depth, temperature, flow, and amount of dissolved nutrients.
- Freshwater ecosystems can be divided into three main categories: rivers and streams, lakes and ponds, and freshwater wetlands.
- Estuaries serve as spawning and nursery grounds for many ecologically and commercially important fish and shellfish species.
- Ecologists divide the ocean into zones based on depth and distance from shore.

benthos (p. 96)
plankton (p. 97)
wetland (p. 97)
estuary (p. 98)

4 CHECK Understanding

Assess the Big idea Interdependence in Nature

Write an answer to the question below.

Q: How do abiotic and biotic factors shape an ecosystem?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each question should be one or two paragraphs. To help you begin, read the **Hints** below the questions.

1. **How do abiotic factors determine which organisms are involved in primary succession after a volcanic eruption?**

   Hint Volcanic eruptions deposit large amounts of volcanic rock and ash.

   Hint Volcanoes can be found in many different biomes.

2. **How does introducing an invasive species into an ecosystem demonstrate the competitive exclusion principle?**

   Hint Introduced species often have no predators or parasites in their new environments. How might this affect their competition with native species?

3. **What type of symbiosis occurs between a cow and the bacteria in its stomach?**

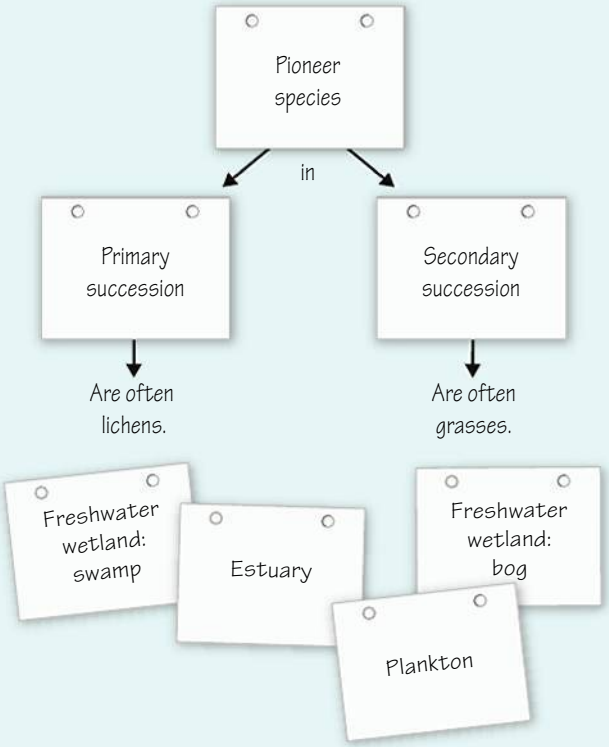
   Hint The bacteria can digest cellulose, but the cow cannot.

Foundations for Learning Wrap-Up

Use the index cards you prepared when you started the chapter as tools to organize your thoughts about ecosystems and communities.

Activity 1 Working with a partner, take turns picking vocabulary index cards at random. Identify each term as a biotic factor or an abiotic factor in an ecosystem and explain why it is biotic or abiotic.

Activity 2 Working in a small group, divide all the vocabulary and ecosystem cards into groups by lesson. Construct concept maps by arranging the cards on a table and explain how the terms are related.



4.1 Climate

Understand Key Concepts

1. The average temperature in a certain valley is usually higher than that of the surrounding countryside. This means that the valley has its own

a. weather. **c.** rainfall.

b. climate. **d.** microclimate.

Test-Taking Tip

Choose Among Similar Answers Sometimes questions have answer choices that are similar to each other. It may help if you first define each of the answer choices. In question 2, answer choices **a, b,** and **d** are similar. The correct answer is **d** because microclimate refers to the conditions in a small area. A valley is a small area.

2. Distinguish between *weather* and *climate*.

Think Critically

3. **Apply Concepts** Based on the relative positions of the sun and Earth, explain why Earth has climate zones and seasons.

4.2 Niches and Community Interactions

Understand Key Concepts

4. The relationship between a tick and its host is an example of

a. mutualism. **c.** commensalism.

b. parasitism. **d.** succession.

5. What is the competitive exclusion principle?

Think Critically

6. **Compare and Contrast** How are predation and parasitism different?

4.3 Succession

Understand Key Concepts

7. Fires, hurricanes, and other natural disturbances can result in

a. commensalism. **c.** parasitism.

b. competition. **d.** succession.

8. The first organisms to repopulate an area affected by a volcanic eruption are called

a. keystone species. **c.** primary producers.

b. climax species. **d.** pioneer species.

9. Describe two major causes of ecological succession.

Think Critically

10. **Relate Cause and Effect** Why does secondary succession usually proceed faster than primary succession?

4.4 Biomes

Understanding Key Concepts

11. Permafrost characterizes the biome called

a. taiga. **c.** savanna.

b. boreal forest. **d.** tundra.

12. Why are there generally few plants in a desert?

Think Critically

13. **Apply Concepts** Although the amount of precipitation is low, most parts of the tundra are very wet during the summer. How would you explain this apparent contradiction?

4 CHECK Understanding

4.5 Aquatic Ecosystems

Understanding Key Concepts

14. Kelp forests and coral reefs are types of communities found in which marine ecosystem?

a. intertidal zone

b. open ocean photic zone

c. coastal ocean

d. open ocean aphotic zone

15. How are salt marshes and mangrove swamps alike?

Think Critically

16. Infer The deep ocean lies within the aphotic zone and is very cold. What are some unique characteristics that might enable animals to live in the deep ocean?

Connecting Concepts

Use Science Graphics

The following table presents primary productivity (measured in grams of organic matter produced per year per square meter) for several ecosystems. Use the table below to answer questions 17 and 18.

Productivity of Aquatic and Land Ecosystems

Ecosystem	Average Primary Productivity
Aquatic Ecosystems	
Coral reef	2500
Estuary	1800
Open ocean	125
Land Ecosystems	
Tropical rain forest	2200
Tropical savanna	900
Tundra	90

17. Interpret Tables According to the table, which ecosystem is most productive?

18. Infer The open ocean is among the least productive ecosystems per square meter. But most of Earth's photosynthesis takes place in its photic zone. How might the amount of water that covers Earth explain why these two facts can both be true?

solve the CHAPTER MYSTERY

THE WOLF EFFECT

Removing wolves from Yellowstone National Park contributed to an increase in the number of elk. These elk grazed so heavily that the seedlings and shoots of aspens, willows, and other trees could not grow. This was especially a problem along streams. Fewer trees meant beavers built fewer dams, which led to an increase in runoff and erosion. Aquatic food webs broke down, affecting birds, fish, and other animals. The recent reintroduction of wolves has caused a decrease in the overall elk population. This increase seems to have reduced elk grazing along certain streams. That may be in part because wolves are killing more elk. It may also be in part because elk have learned to stay away from places like stream banks and valleys. Wolves can attack them most easily in these areas.

In recent years, researchers have shown that streamside vegetation is exhibiting secondary succession. The aspen and willow trees are starting to grow back. There have been numerous other changes as well. Fewer elk mean more food for smaller animals. The increase in small prey, in turn, has brought diverse predators into the community. Carcasses abandoned by the wolves provide food for scavengers. In short, organisms from every trophic level have been affected by the Yellowstone wolves.

1. Predict The Yellowstone wolf and elk are linked through a predator-prey relationship. If a disease were to strike the elk population, how would this affect the wolves?

2. Apply Concepts Why might you consider the wolves to be a keystone species?

Untamed Science **Never Stop Exploring Your World.** The mystery of the Yellowstone wolves is just the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

Standardized Test Prep

Multiple Choice

1. The factor that generally has the greatest effect on determining a region's climate is its
A longitude.
B abundant plant species.
C distance from the equator.
D closeness to a river.

2. All of the following are abiotic factors that affect global climate EXCEPT
A latitude.
B longitude.
C solar energy.
D ocean currents.

3. The way an organism makes its living, including its interactions with biotic and abiotic factors of its environment, is called the organism's
A habitat.
B niche.
C lifestyle.
D biome.

4. If a newly introduced species fills a niche that is normally occupied by a native species, the two species compete. One of the species may die out as a result of
A competitive exclusion.
B predation.
C commensalism.
D mutualism.

5. Photosynthetic algae are MOST likely to be found in
A the open-ocean benthic zone.
B the aphotic zone.
C the photic zone.
D ocean trenches.

6. The water in an estuary is
A salt water only.
B poor in nutrients.
C fresh water only.
D a mixture of fresh water and salt water.

7. In which biome do organisms have the greatest tolerance to dry conditions?
A tundra
B desert
C tropical savanna
D boreal forest

Questions 8–9

Month-by-month climate data for the city of Lillehammer, Norway, is shown in the table below.

Climate Data for Lillehammer, Norway

Month	Average Temperature (°C)	Average Precipitation (mm)
Jan.	−8.1	38.1
Feb.	−6.2	27.9
Mar.	−3.9	30.5
Apr.	3.3	35.6
May	8.9	45.7
June	13.9	63.5
July	16.4	81.3
Aug.	14.2	88.9
Sept.	9.5	58.4
Oct.	3.9	63.5
Nov.	−3.8	50.8
Dec.	−6.1	48.3

8. Which type of graph would be BEST suited to showing the precipitation data from the table?
A bar graph
B pictograph
C pie chart
D scatter plot

9. For a given set of data, the range is the difference between highest and lowest points. The average annual temperature range, in °C, for Lillehammer is approximately
A −8.
B 8.5.
C 16.5.
D 24.5.

Open-Ended Response

10. Why are lichens especially well adapted to play the role of pioneer organisms in an ecological succession?

If You Have Trouble With . . .										
Question	1	2	3	4	5	6	7	8	9	10
See Lesson	4.1	4.1	4.2	4.2	4.5	4.5	4.4	4.1	4.1	4.3

5 Populations

Big idea

Interdependence in Nature

Q: What factors contribute to changes in populations?

BIOLOGY.com Search Chapter 5 GO • Flash Cards

INSIDE:

Millions of red crabs live on Christmas Island in the Indian Ocean. Each year, all of the adult crabs move from forest to sea to breed.

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

A PLAGUE OF RABBITS

In 1859, an Australian farmer released 24 English rabbits on his ranch. In ten years, more than 2 million rabbits were hunted on that ranch alone! Soon, millions of rabbits spread across the country and caused lots of trouble. They ate native plants that used to feed native animals. The loss of those food plants pushed native animals close to extinction. The rabbits also made life miserable for sheep and cattle ranchers. Yet those rabbits weren't a problem in England. Why were they such a problem in Australia? Could they be stopped? How?

Read for Mystery Clues As you read this chapter, look for clues to help you predict why this rabbit population grew so much. Think about factors that affect population growth. Then, solve the mystery at the end of the chapter.

FOUNDATIONS for Learning

Before you read this chapter, read the lesson titles and headings. Then, fold a piece of paper into three columns. In the first column, list what you know about populations. In the second column, write questions about what you want to learn. In the third column, you will write what you have learned. There are two activities at the end of the chapter that will require you to use your paper to answer the question: What factors contribute to changes in populations?

5.1 How Populations Grow

Key Questions

- ***How do ecologists study populations?***
- ***What factors affect population growth?***
- ***What happens during exponential growth?***
- ***What is logistic growth?***

BUILD Understanding

Concept Map As you read, make a concept map that organizes the information in this lesson.

In Your Workbook Go to your workbook for help in completing the concept map. Complete the concept map for Lesson 5.1.

Describing Populations

About 60 years ago, a fish farmer in Florida tossed some hydrilla plants into a canal. These few plants, which were brought here from Asia, reproduced quickly. Today, hydrilla can be found across Florida and many other states. Because hydrilla grow so thickly, they kill other plants and animals. Why do hydrilla grow so quickly?

Ecologists try to answer such questions. Ecologists study a population's range, density, growth rate, and age structure.

Geographic Range A population's geographic range describes the spaces where it lives. Different populations can have very different ranges. For example, the range of a bacterial population may be tiny. But the population of cod in the western Atlantic Ocean ranges from Greenland to North Carolina.

Density and Distribution Population density is the number of individuals of a species per unit area. In a meadow, for example, you might find a dense population of grasses but a less dense population of spiders. Population distribution describes how the organisms are spread across their range. The distribution of a population may be random, uniform, or clumped.

Growth Rate A population's growth rate tells you if the population size is getting bigger, smaller, or staying the same. The population of hydrilla in Florida has a very high growth rate. Populations can also decrease in size. The cod population, which is decreasing, has a negative growth rate.

Invasive Hydrilla Hydrilla has spread throughout most of Florida in just a few decades. Efforts to control the waterweed cost millions of dollars a year.

Age Structure The **age structure** of a population describes the number of males and females of each age in the population. Age structure is important because in animals only the females between certain ages can reproduce.

Key Question How do ecologists study populations?
Ecologists study a population's range, density, growth rate, and age structure.

BUILD Vocabulary

age structure
the numbers of males and females in different age groups of a population

immigration
the movement of individuals into an area occupied by an existing population

emigration
the movement of individuals out of an area

exponential growth
a growth pattern in which the individuals in a population reproduce at a constant rate

RELATED WORD FORMS

An exponent refers to the number of times a number is multiplied by itself. The adjective *exponential* describes something that can be expressed using exponents.

Population Growth

The size of a population changes based on how many individuals are added to it or removed from it. How are individuals added or removed?

Birthrate and Death Rate A population may grow if more individuals are born than die in any period of time. In this case, the birthrate is higher than the death rate. If the death rate is higher, the population may shrink. If these rates are about the same, the population may stay the same size.

Immigration and Emigration When individuals move into a population's range, the process is called **immigration** (im uh GRAY shun). When individuals move out of the range, it is called **emigration** (em uh GRAY shun). If immigration rates are higher than emigration rates, the population will grow.

Key Question What factors affect population growth?
Population growth is affected by birthrate and death rate. It can also be affected by immigration and emigration.

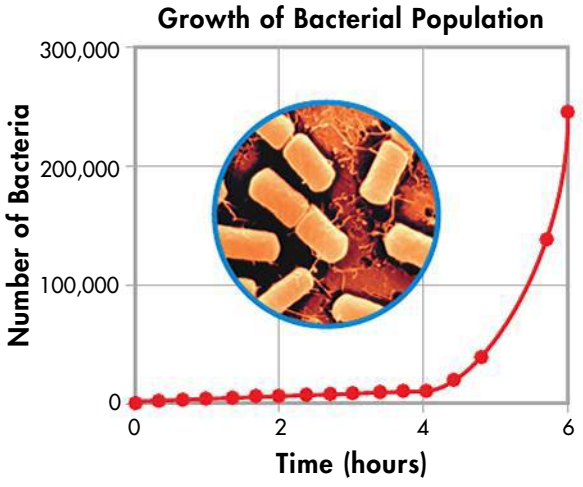
Exponential Growth

Imagine that a population has all the food and space it needs. It also has protection from predators and disease. Imagine also that its waste products are all removed. Under these conditions, the population will grow.

Organisms That Reproduce Rapidly Imagine a single bacterium that divides to form two cells every 20 minutes. Those two cells divide to form four cells. Those four cells divide again. So, after three 20-minute periods, there are $2 \times 2 \times 2$, or 8 cells, which can also be written using an exponent: 2^3 cells.

This situation is called exponential (eks poh NEN shul) growth. In **exponential growth,** the larger a population gets, the more quickly it grows. When you graph the growth, the graph is in the shape of a J.

Model of Exponential Growth



Exponential Growth When there are plenty of resources and few predators or diseases, populations will grow exponentially. This graph shows the characteristic J-shaped curve of exponential growth.

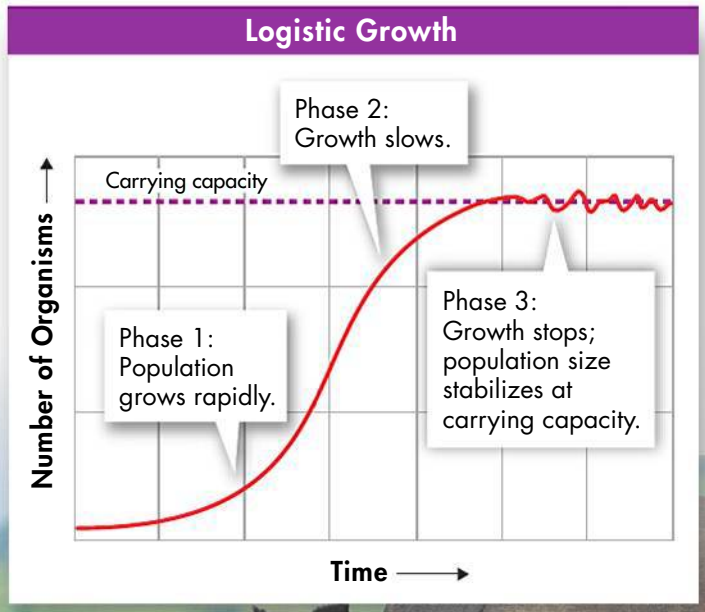
Organisms in New Environments Does exponential growth ever happen in nature? Yes! That's what happened with hydrilla, and with many other species that humans have introduced into new habitats. When a species is moved into a new habitat, its population often grows exponentially for a time. But think about this situation for a minute. Can this growth continue without stopping?

Key Question What happens during exponential growth?
In exponential growth, the larger a population gets, the more quickly it grows.

Logistic Growth

Exponential growth presents us with a puzzle. Obviously, bacteria and hydrilla don't cover the planet. This means that populations in the real world don't grow exponentially for very long. Sooner or later, population growth slows down. But why?

Phases of Growth To begin to answer this question, let's see what happens when a few individuals are brought into a new area. Usually the population will go through three phases. You have read a bit about the first phase—exponential growth. In the next phases, the growth slows and eventually stops.

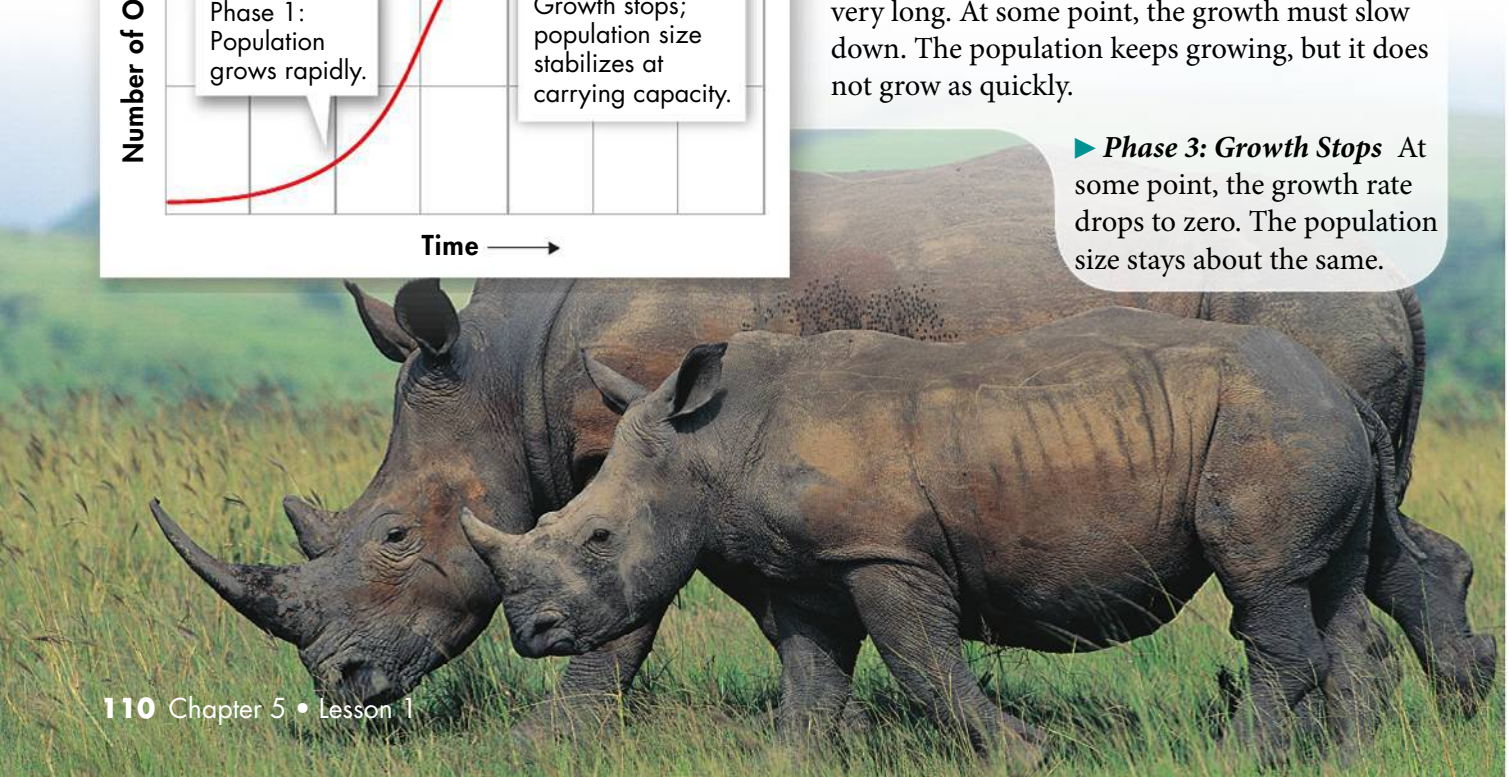


Logistic Growth Population growth slows down as resources become limited. This graph shows the characteristic S-shaped curve of logistic growth.

▶ ***Phase 1: Exponential Growth*** After a short time, the population begins to grow exponentially. There is plenty of food. There is plenty of space. The death rate is low. The birthrate is high. The rate of growth increases more and more quickly.

▶ ***Phase 2: Growth Slows Down*** In most populations, exponential growth does not last very long. At some point, the growth must slow down. The population keeps growing, but it does not grow as quickly.

▶ ***Phase 3: Growth Stops*** At some point, the growth rate drops to zero. The population size stays about the same.



The Logistic Growth Curve When a population's growth slows down and stops, it is called **logistic growth.** A logistic growth curve is shaped like an S.

What kinds of changes in a population cause logistic growth? A population grows when the number of organisms added to the population is more than the number of organisms that leave the population. Population growth may slow for several reasons. Growth may slow because the birthrate slows. Growth may slow because the death rate increases. Immigration and emigration can also affect growth rates. If immigration decreases or emigration increases, growth will slow.

Carrying Capacity In the third phase of logistic growth, the population stops growing. Population growth stops when the birthrate and death rate are the same and when immigration equals emigration. Look again at the logistic growth curve. There is a broken, horizontal line in the graph where the population size stays about the same. This population size is the largest number of individuals an area can support. The largest number of individuals that an area can support is called the **carrying capacity.** The population size may go up or down somewhat. However, the size stays very near the carrying capacity.

Key Question What is logistic growth?
Logistic growth happens when the growth of a population begins as exponential growth and then slows and stops.

BUILD Vocabulary

logistic growth
a growth pattern in which a population's growth rate slows or stops, following a period of exponential growth

carrying capacity
the largest number of individuals of a population that a given environment can support

RELATED WORD FORMS

The word *logistics* means the way someone handles the resources of a project or event. The adjective *logistic* is used in this sense to describe growth that can be supported by the available resources.

CHECK Understanding

Apply Understanding

Use the highlighted words from the lesson to complete each sentence correctly.

1. _____ sometimes happens when a new kind of organism is introduced in an area.
2. The number of males and females of each age group in a certain population is called the _____.
3. The number of organisms an area can support over a long period of time is called the _____.

Critical Thinking

4. **Relate Cause and Effect** More dandelion seedlings develop in a lawn than dandelion plants are pulled. What is likely to happen to the lawn's dandelion population?
5. **Explain** Describe logistic growth.
6. **Apply Concepts** A few European gypsy moths were accidentally released from a laboratory near Boston. Describe what might have happened to the population over the next several years.
7. **Write to Learn** Answer the first clue of the mystery. Think about the different phases of population growth.

MYSTERY CLUE

What kind of growth is the rabbit population in Australia demonstrating? Why does that cause problems? (Hint: See p. 110.)

BIOLOGY.com Search Lesson 5.1 GO • Lesson Assessment

5.2 Limits to Growth

Key Questions

- ***What factors determine carrying capacity?***
- ***What limiting factors depend on population density?***
- ***What limiting factors do not usually depend on population density?***

BUILD Understanding

Preview Before you read this lesson, write down the headings and look at the figures. As you read, write the main idea under each heading.

In Your Workbook Go to your workbook for help previewing the lesson.

Limiting Factors

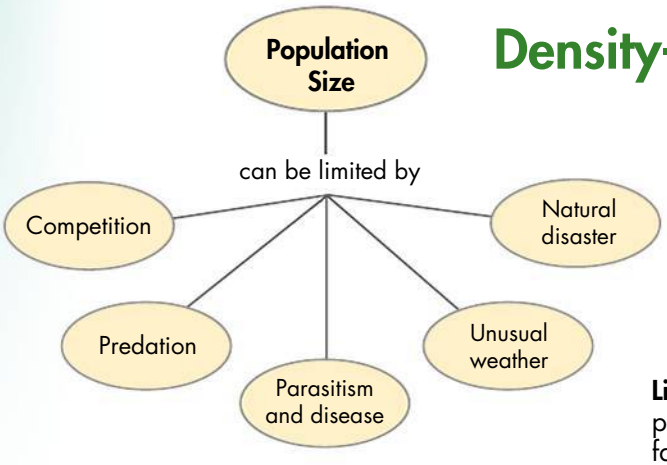
Now that you have seen *how* populations tend to grow in nature, you can explore *why* they grow as they do. What factors cause the growth to slow down? What determines the carrying capacity of an environment for a species?

Think about the hydrilla discussed in Lesson 5.1. In Asia, the population reached its carrying capacity. Then, it stopped growing. In the United States, hydrilla just keeps growing. The same thing happened when a few nonnative gypsy moths were accidentally released near Boston. Within a few years, these plant-eating pests had spread across the northeastern United States. Gypsy moths and hydrilla do not seem to have a carrying capacity. What is happening?

A **limiting factor** is any factor that controls the size of a population. The number of predators in an area may be a limiting factor. How much food is available may be a limiting factor. Limiting factors keep most natural populations from growing out of control. Limiting factors determine the carrying capacity of an environment for a species.

Some factors depend on the density of the population. They depend on how many individuals live in one place. Other factors affect a population no matter how many individuals live in an area.

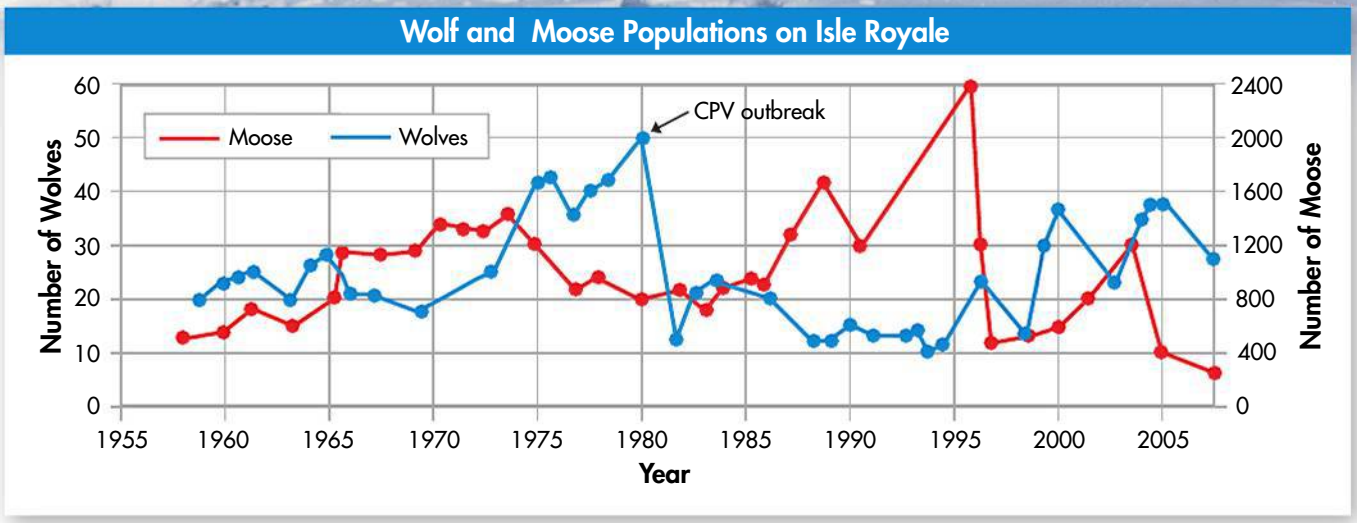
Key Question What factors determine carrying capacity?
Limiting factors determine the carrying capacity of a population.



Limiting Factors Many factors can limit population growth. Some of these factors depend on population density. Others do not.

Density-Dependent Limiting Factors

Some limiting factors affect populations most when the individuals live close together. These limiting factors depend on the population density and are called **density-dependent limiting factors.** There are several different kinds of density-dependent limiting factors.



Moose and Wolf Populations on Isle Royale Moose and wolves on Isle Royale affect each other's population growth. In this case, the moose population was also affected by changes in food supply. The wolf population was also impacted by a virus (CPV) in 1980.

Predators One important density-dependent factor is the relationship between predators and prey. The populations of moose and wolves on Isle Royale in Lake Superior are one example. When the moose population is high, wolves catch them easily. So the wolf population then grows. More wolves mean that more moose are killed than are born. The moose population falls. With fewer moose, the wolves starve. The wolf population falls. Eventually, the moose population rises again, and the cycle repeats.

People can also limit population sizes. In New England, people are predators of codfish. People catch more and more fish each year. The cod population has gotten much smaller. If people killed fewer cod, the population could rise again. Scientists are studying the cod population. They want to learn how many fish can be caught each year without risking the entire population.

BUILD Vocabulary

limiting factor
a factor that causes the growth of a population to decrease

density-dependent limiting factor
a limiting factor that depends on population size

ACADEMIC WORDS

You learned that the word *factor* is a feature that contributes to an event or result. A limiting factor, however, is a feature that contributes to a change in population growth.

Parasites The ticks on this hedgehog are parasites. They can spread diseases to the hedgehog.

Herbivores From the plant's point of view, herbivores are predators. So it makes sense that the populations of herbivores and plants go up and down over time. Moose on Isle Royale eat balsam fir. When there are a lot of moose living in parts of Isle Royale, the fir population falls. Then, the moose begin to starve. As the moose population drops, the fir population goes back up.

Parasites and Disease Parasites and organisms that cause disease feed on their hosts. This feeding weakens the host and can cause disease or death. When hosts live close together, the hosts come into contact with each other more often. Therefore, diseases and parasites spread more easily from one host to the next. The wolf population on Isle Royale dropped quickly around 1980. This decline was due to a viral disease that spread quickly through the large, dense wolf population. Only three females and ten males survived.

Competition An area can support only a certain number of organisms. When an area is crowded, organisms compete for food, water, space, sunlight, and other essentials. Some individuals may not get enough to live. Others may not get enough to raise offspring. Competition can lower birthrates, increase death rates, or both.

Competition is a density-dependent limiting factor because resources are used up faster if there are more individuals that need them. Space and food are often related to each other. Many grazing animals compete for territories. They use the territories to graze and raise offspring. If they do not have a territory, then they cannot find a mate and produce offspring.

Overcrowding In some populations, overcrowding causes fighting. Too much fighting may lead to stress. Stress can make it harder for the body to fight sickness. In some cases, stress can even cause females to kill their offspring. So, stress from overcrowding can lower birthrates, raise death rates, and increase rates of emigration.

Key Question What limiting factors depend on population density?

Competition depends on population density. Predators, herbivores, parasites, and diseases affect crowded populations more. Stress can also affect a dense population.

BUILD Vocabulary

density-independent limiting factor
a limiting factor that affects all populations in similar ways, regardless of population size

PREFIXES
The prefix *in-* in *independent* means "not." Density-independent limiting factors do not depend on the density of the population.

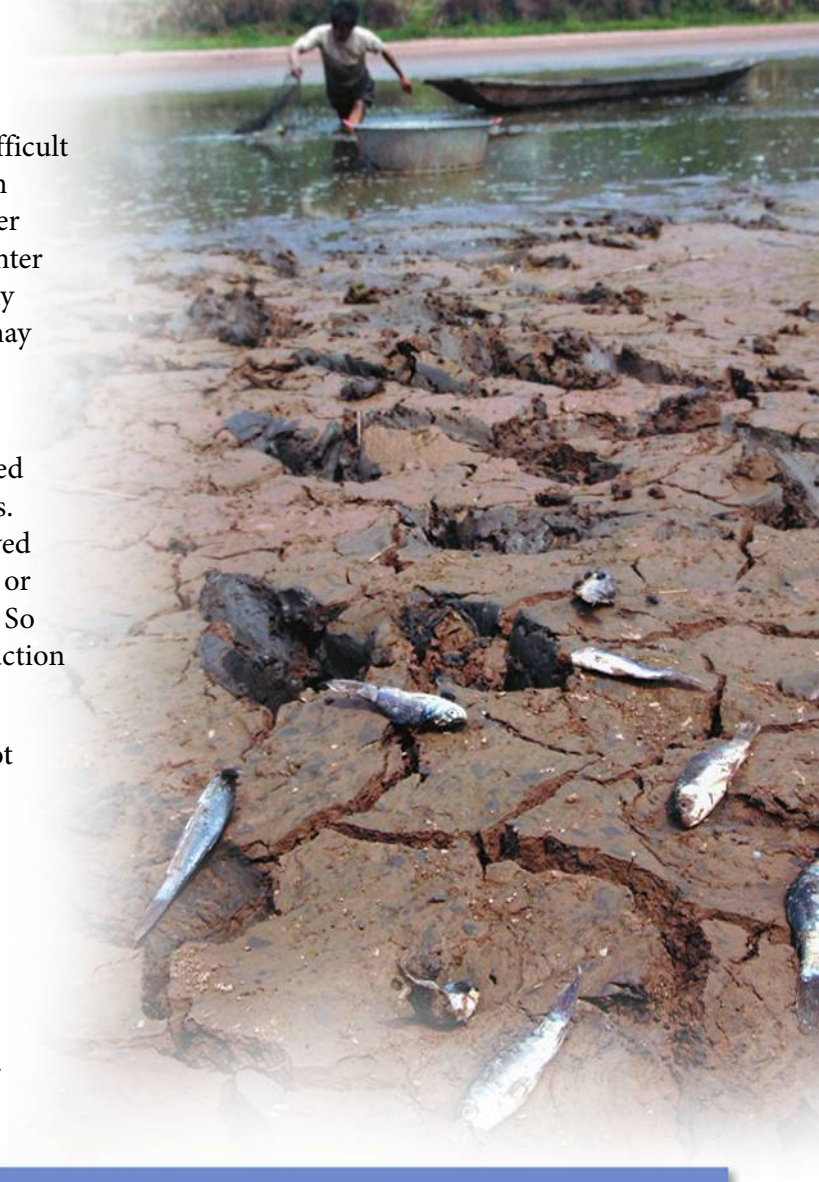
Density-Independent Limiting Factors

Some limiting factors do not depend on how many individuals live close together. These factors affect all populations in almost the same ways and are called **density-independent limiting factors.** Bad weather, such as a hurricane or drought, is a density-independent limiting factor. Natural disasters, such as wildfires, do not depend on density either. Large storms can sometimes kill most of a population. For example, insects may be washed away by a heavy rain.

True Density Independence? It is sometimes difficult to say that a factor is truly density independent. On Isle Royale, the moose population grew quickly after the wolf population dropped. Then, a very cold winter came. Snow covered the plants the moose ate. Many moose died. If there had been fewer moose, they may have found enough food. In this case, two factors worked together to limit the population.

Controlling Introduced Species People have tried many things to control hydrilla in the United States. Density-independent limiting factors have not solved the problem. Using chemicals and machines to kill or remove the hydrilla have worked only temporarily. So far, the best plan of control seems to be the introduction of sterilized grass carp fish to eat the plants.

Key Question What limiting factors do not usually depend on population density?
Unusual weather and natural disasters can act as density-independent limiting factors.



Effects of a Severe Drought on a Population During a drought, dead fish lie rotting on the banks of the Paraná de Manaquiri River in Brazil.

CHECK Understanding

Use the highlighted words from the lesson to complete each sentence correctly.

1. A flood is an example of a _____ because it usually affects all populations in the same way.
2. Limiting factors that affect large, dense populations more than small, scattered populations are called _____.

Critical Thinking

3. **Apply Concepts** How do limiting factors affect the growth of populations?
4. **Relate Cause and Effect** What is the relationship between competition and population size?
5. **Apply Concepts** Arctic foxes eat lemmings. What is likely to happen to the lemming population if the arctic fox population were to increase quickly?
6. **Write to Learn** Answer the second clue of the mystery. Think about factors that might be different in England than in Australia.

MYSTERY CLUE

What factors do you think could limit the size of a rabbit population? (Hint: See p. 114.)

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How Does Competition Affect Growth?

Individuals who live near each other compete for what they need. There is usually only so much food, water, space, and sunlight to go around. The individuals who get enough of these resources live longer, healthier lives. They tend to produce more offspring. Individuals who do not get enough may not survive. Some individuals may get enough food or water to survive but not enough to raise offspring. In this way, competition can affect the size of a population.

Competition is a density-dependent limiting factor. Resources are used up more quickly by large, dense populations. Small, scattered populations do not use as many resources. In these populations, competition is not usually a limiting factor.

In Lesson 5.2, you learned about competition and other limiting factors. In this activity, you will explore how competition affects the growth of bean sprouts.

1. Label two paper cups 3 and 15. Prepare the two cups by completing the following steps:
   - Make five or six small holes in the bottom of each cup.
   - Fill each cup two-thirds full with potting soil.
   - Plant 3 bean seeds in cup 3.
   - Plant 15 bean seeds in cup 15.
2. Water both cups so that the soil is moist but not wet.
3. Put the cups in a location that gets bright, indirect light. Water the cups equally as needed.
4. Count the seedlings every other day for two weeks. Draw a chart like the one below to record your data. (You planted your seeds on Day 0.)

Analyze and Conclude

1. Observe What differences did you observe between the two cups?

In Your Workbook Get more help for this activity in your workbook.

	Day 2	Day 4	Day 6	Day 8	Day 10	Day 12	Day 14
Date							
Cup 3							
Cup 15							

5.3 Human Population Growth

Historical Overview

For most of human history, the human population grew slowly. Food was hard to find. The death rate was high because of predators and disease. Today, four human babies are born every second. The human population could reach 9 billion in your lifetime. What changes have made it possible for the human population to grow so quickly?

Exponential Human Population Growth As life became easier, the human population began to grow more rapidly. During the Industrial Revolution in the 1800s, people learned how to ship goods around the world. Food supplies became more reliable. Healthcare and medicine improved. People learned more about sanitation and nutrition. Because of all these improvements, death rates dropped. But the birthrate stayed very high. This combination of lower death rates and high birthrates led to exponential growth of the human population.

World Population Growth Slows The human population growth rate was highest around 1962–1963. The population is still growing very rapidly. However, the rate of growth is slowing.

It took 123 years for the population to go from 1 billion in 1804 to 2 billion in 1927. It took only 33 years to reach 3 billion. The time it took to add another billion people continued to decrease until 1999. Since then, the growth rate has slowed. What has been happening to slow human growth?

Key Question How has the size of the human population changed over time? **For a long time, the population grew slowly. In the 1800s, the population began to grow exponentially.**

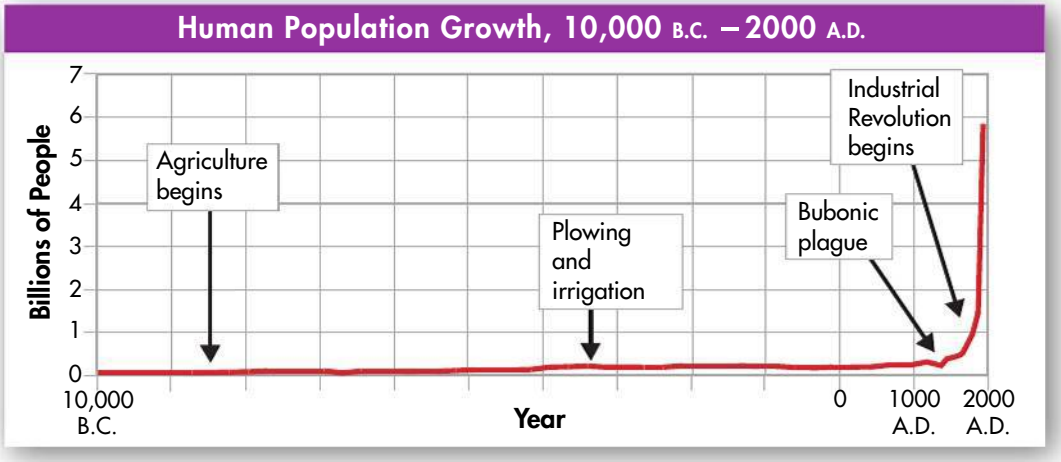
Key Questions

- ***How has the size of the human population changed over time?***
- ***Why do population growth rates differ among countries?***

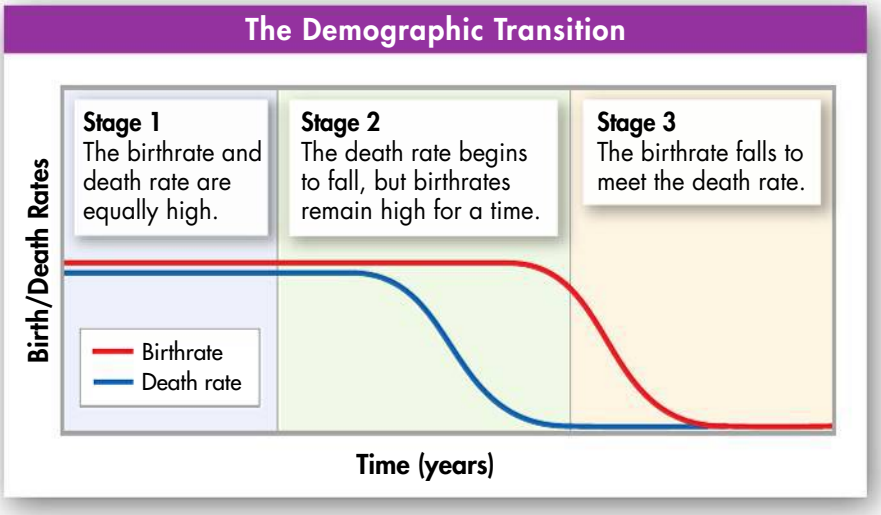
BUILD Understanding

Preview Visuals Before you read, preview the graphs throughout the lesson. Make a list of questions about the graphs. Then, as you read, write down the answers to your questions.

In Your Workbook Go to your workbook to review the graphs.



Human Population Growth Over Time For a long time, the human population grew very slowly. Technological advances lowered death rates. Then, the global population began to increase much more quickly.



The Demographic Transition
Stage 1: Birthrates and death rates are high for most of history.
Stage 2: Advances in nutrition, sanitation, and medicine lower death rates. Birthrates remain high. There are many more births than deaths. The population increases exponentially.
Stage 3: As living standards rise, families have fewer children and the birthrate falls. Population growth slows. The demographic transition is complete when the birthrate meets the death rate.

Patterns of Human Population Growth

The world population growth rate has slowed a lot recently. In some countries, however, the growth rate is still high. In fact, most of the world's population growth is happening in only ten countries. India and China are leading the growth.

BUILD Vocabulary

demography
the scientific study of human populations

demographic transition
a change in a population from high birthrates and death rates to low birthrates and death rates

PREFIXES
The prefix *demo-* in *demography* and *demographic* comes from the Greek word *demos,* which means "people." This prefix is also used in *democracy*.

Scientists have identified several things that affect population growth. The scientific study of human populations is called **demography** (duh MAH gruh fee). Demography looks at characteristics of human populations. It tries to explain how those populations will change over time. Scientists study birthrates, death rates, and the age structure of a population. They use this information to explain why some countries have high growth rates and some countries grow more slowly.

The Demographic Transition

For a long time, human societies had very high birthrates and death rates. Then, death rates dropped and birthrates remained high. Over the past century, birthrates in the United States, Japan, and much of Europe also fell. The growth rates in these countries slowed dramatically. These countries have completed the demographic transition. In the **demographic transition,** a population changes from having high birthrates and death rates to having low birthrates and death rates. There are three stages to the transition, as shown above.

Age Structure and Population Growth

The age structure in a country helps predict how quickly a population will grow. In the United States, there are nearly equal numbers of people in each age group. This structure suggests that the population of the United States will grow slowly. In countries such as Guatemala, there are many more young children than teenagers. There are many more teenagers than adults. The population of Guatemala may double in the next 30 years.

Future Population Growth People who study demography look at many factors to predict how the human population will grow. Age structure is one important factor. They also study how diseases affect death rates. Right now, AIDS is causing very high death rates in Africa and parts of Asia.

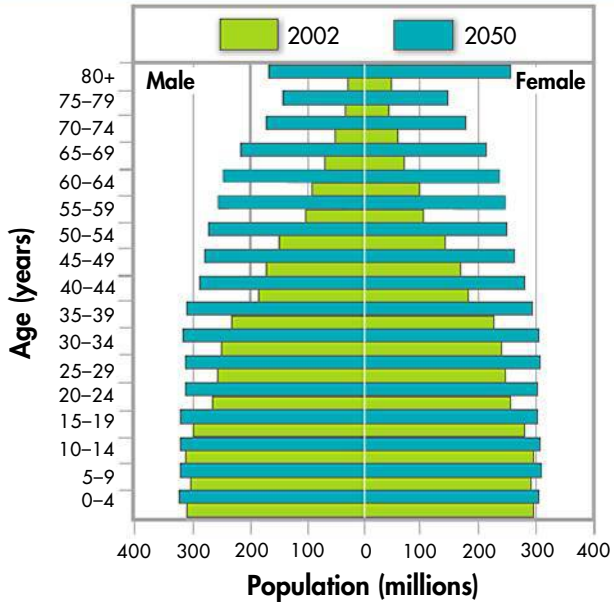
The world population may reach 9 billion people by the year 2050. Will the human population level out to a logistic growth curve? Countries growing rapidly right now would need to complete the demographic transition.

It is expected that the world population will grow more slowly over the next 50 years than it did over the last 50 years. The growth rate will probably still be higher than zero in 2050. If so, our population will continue to grow. In the next chapter, you will learn about the effect of human population growth on the biosphere.

Key Question Why do population growth rates differ among countries?

Birthrates, death rates, and age structure are different in different countries. These differences cause some countries to have high growth rates and others to have low growth rates.

Age Structure of World Population



A Growing Population The information for this graph was taken from the U.S. Census Bureau, International Database. The graph shows the projected age structure of the world population in 2050. The photo above shows a housing complex in Hong Kong, China. Each apartment building is home to thousands of people.

CHECK Understanding

Apply Vocabulary

Use the highlighted terms from the lesson to complete each sentence correctly.

1. People who study _____ look at characteristics, such as age structure, death rate, and birthrate to predict how human populations will change.
2. In the third stage of the _____, the birthrate and death rate are equal.

Critical Thinking

3. **Apply Concepts** If every married couple in a country were to decide to have only one child, what would happen to the country's population growth?
4. **Relate Cause and Effect** The human population grew very slowly for most of human history. In about 1800, the population began growing exponentially. What factors contributed to this growth pattern?
5. **Quick Write** In one or two paragraphs, describe the three stages of demographic transition. Explain how the population growth rate changes at each stage.

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Pre-Lab: The Growth Cycle of Yeast

Problem What type of population growth occurs in a yeast culture?

Materials yeast culture, stirring rod, dropper pipettes, microscope slides, coverslips, microscope, 10-mL graduated cylinder, test tubes, test-tube rack, graph paper

Lab Manual Chapter 5 Lab

Skills Measure, Calculate, Interpret Graphs

Connect to the Big idea Populations depend on, and are limited by, their environments. A population can grow when its members have the resources they need to survive and reproduce. Factors that can limit those resources include natural disasters, such as forest fires, and competition from other species. Predation and disease are also limiting factors for populations.

In nature, populations often experience cycles of growth and decline. In this lab, you will investigate whether such a cycle occurs in yeast populations.

Background Questions

a. Review What is the carrying capacity of a population?

b. Sequence Briefly describe the three phases of logistic growth.

c. Relate Cause and Effect Describe two different ways that a population might achieve a growth rate of zero.

d. Classify After two weeks of hot and sunny days with very little rain, the blades of grass in a backyard began to wither and die. Were any of the factors that caused the decline of the grass population dependent on density? Explain.

Pre-Lab Questions

Preview the procedure in the lab manual.

1. Infer Why was grape juice used to prepare the yeast cultures instead of plain water?

2. Calculate Suppose you have to do one dilution of your culture before you are able to count the yeast cells. If you count 21 yeast cells in the diluted sample, how many yeast cells were in the same area of the undiluted sample? MATH

3. Predict What do you think will happen to a yeast population between Day 3 and Day 7? Give reasons for your answer.

BIOLOGY.com Search Chapter 5 GO

Visit Chapter 5 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Join the Untamed Science crew as they learn the latest techniques for counting populations.

Art in Motion View a short animation that brings age-structure diagrams to life.

Art Review Review your understanding of limiting factors with this drag-and-drop activity.

InterActive Art Manipulate factors such as starting population size, birthrate, and death rate to see how they would impact moose and wolf populations over time.

CHAPTER 5 Summary

5.1 How Populations Grow

- Ecologists study a population's range, density, growth rate, and age structure.
- Population growth is affected by birthrate and death rate. It can also be affected by immigration and emigration.
- In exponential growth, the population grows more and more quickly.
- Logistic growth happens when the growth of a population slows and then stops.

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age structure (p. 109)
immigration (p. 109)
emigration (p. 109)
exponential growth (p. 109)
logistic growth (p. 111)
carrying capacity (p. 111)

5.2 Limits to Growth

- Limiting factors determine the carrying capacity of a population.
- Competition depends on population density. Predators, herbivores, parasites, and diseases affect crowded populations more than small, scattered populations. Stress can also affect a dense population.
- Unusual weather and natural disasters can act as density-independent limiting factors.

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limiting factor (p. 112)
density-dependent limiting factor (p. 112)
density-independent limiting factor (p. 114)

5.3 Human Population Growth

- For a long time, the population grew slowly. In the 1800s, the population began to grow exponentially.

- Birthrates and death rates are different in different countries. The age structures are different. Countries with high birthrates and low death rates are growing quickly. The United States, Japan, and much of Europe have completed the demographic transition, and their growth rates have slowed.

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demography (p. 118)
demographic transition (p. 118)

5 CHECK Understanding

Assess the Big idea Interdependence in Nature

Write an answer to the question below.

Q: What factors contribute to changes in populations?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs long. To help you begin, read the **Hints** below each of the questions.

1. **Why should people be cautious about introducing organisms into new environments?**

   Hint When organisms are introduced into new environments, they may not face natural predators.

   Hint A limiting factor is a factor that controls the growth of a population.

2. **Natural populations do not grow exponentially for very long. Why not?**

   Hint In exponential growth, the larger a population gets, the faster it grows.

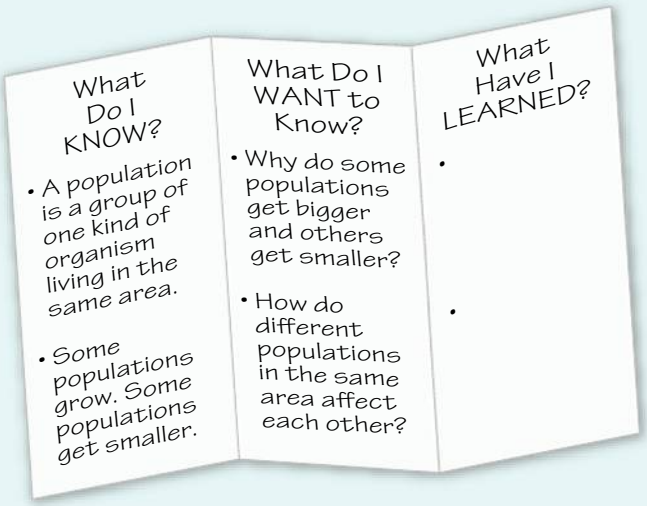
   Hint Carrying capacity is the maximum number of organisms of a species an area can support.

Foundations for Learning Wrap-Up

Use the folded paper chart you made before reading the chapter as a tool to help you organize your thoughts about populations.

Activity 1 On your own, reread the questions you asked at the beginning of the chapter. Write the answers to these questions in the third section of your page, under the heading, What Have I Learned?

Activity 2 Trade charts with a partner. Compare your questions and answers. If one of you had any difficulty answering the questions, find the answers together. Also, double-check the information you each wrote in the first and third columns. Is everything correct? If not, work together to correct your charts.

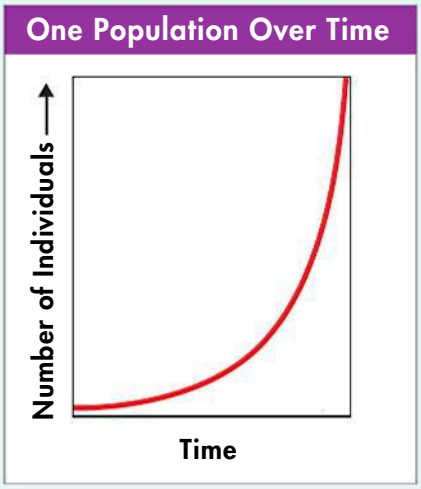


5.1 How Populations Grow

Understanding Key Concepts

1. The space taken up by a population is known as its
   - **a.** growth rate.
   - **b.** geographic range.
   - **c.** age structure.
   - **d.** population density.

2. The graph below represents
   - **a.** carrying capacity.
   - **b.** exponential growth.
   - **c.** logistic growth.
   - **d.** age structure.



Test-Taking Tip

Interpret Visuals Look carefully at visuals. In the graph in question 2, the number of individuals is increasing very quickly over time. The growth rate is increasing over time as well. The graph of logistic growth is shaped like the letter S. The graph of exponential growth is shaped like the letter J. So, answer **c** is not correct. Answer **b** is the correct answer.

3. The largest population size that can survive in a given area is called
   - **a.** logistic growth.
   - **b.** carrying capacity.
   - **c.** exponential growth.
   - **d.** population density.

4. What is the difference between immigration and emigration?

Think Critically

5. **Use Analogies** How is the carrying capacity of a road like the carrying capacity of an ecosystem?

5.2 Limits to Growth

6. A limiting factor that depends on the population size is called a
   - **a.** density-dependent limiting factor.
   - **b.** density-independent limiting factor.
   - **c.** predator-prey relationship.
   - **d.** parasitic relationship.

7. Which of the following is a density-independent limiting factor?
   - **a.** predators
   - **b.** unusual weather
   - **c.** competition
   - **d.** overcrowding

8. Describe how the populations of moose and wolves on Isle Royale affect each other. How does an increase in the population of one affect the population of the other?

9. Why are parasites considered a density-dependent limiting factor?

Think Critically

10. **Predict** What would happen to a population of predators if there were a sudden increase in food for the prey? Explain your answer.

5.3 Human Population Growth

11. What is the scientific study of human populations called?
    - **a.** immigration
    - **b.** emigration
    - **c.** demographic transition
    - **d.** demography

12. What is the last stage of the demographic transition?
    - **a.** The birthrate and death rate are both very high.
    - **b.** The death rate is low, and the birthrate is very high.
    - **c.** The birthrate and death rate are both low.
    - **d.** The birthrate is low, and the death rate is very high.

5 CHECK Understanding

13. Describe the general trend of human population growth over time.

Think Critically

14. **Compare and Contrast** One small town is made up mainly of senior citizens. How would you expect this town's population to change over the next several years? Compare this growth to that of a small town that is made up mostly of newly married couples in their twenties.

Connecting Concepts

Use Science Graphics

The following data come from the United Nations Department of Economic and Social Affairs, Population Division. The table shows when the world population reached 1 billion and when it reached or will reach each additional billion. Use the data table to answer questions 15 and 16.

World Population Milestones

Population (billion)	Year	Time Interval (years)
1	1804	—
2	1927	123
3	1960	33
4	1974	14
5	1987	13
6	1999	12
7	2012	13
8	2027	15
8.9	2050	23

15. **Observe** When did the world population reach 1 billion people? When did it reach 6 billion?

16. **Interpret Tables** Describe the trend in population growth since the 1-billion-people mark.

solve the CHAPTER MYSTERY

A PLAGUE OF RABBITS

Before the farmer let those 24 rabbits go in 1859, Australia had no wild rabbits. So the rabbits had very few predators, parasites, and diseases. Rabbits reproduce quickly. The population jumped from 24 to millions in less than ten years. Large rabbit populations cause a lot of damage.

Australians have tried many things to manage the population. They have tried fencing and poisoning. They have tried to ruin burrows. People have used parasites and disease. In the 1950s, a rabbit virus was deliberately introduced. It killed many rabbits. But eventually, the rabbit populations rose again. Later, a new virus that causes rabbit hemorrhagic disease (RHD) was introduced. Rabbit populations dropped again. In several places, the results were dramatic. Native trees and shrubs returned. It had been thought that these plants were locally extinct! Native animals also recovered. But the RHD virus and rabbits appear to have reached a new balance. Rabbit populations are rising again.

1. **Predict** Wildcats and foxes were also introduced to Australia. These predators have come to depend on rabbits as prey. How do you think wildcats and foxes would be affected by a large drop in the rabbit population?

UntamedScience **Never Stop Exploring Your World.** Finding the solution to the rabbit population mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

Standardized Test Prep

Multiple Choice

1. The movement of individuals into an area is called
A immigration.
B emigration.
C population growth rate.
D population density.

2. All other things being equal, the size of a population will decrease if
A birthrate exceeds the death rate.
B immigration rate exceeds emigration rate.
C death rate exceeds birthrate.
D birthrate equals death rate.

3. Which of the following is NOT an example of a density-dependent limiting factor?
A natural disaster **C** competition
B predator **D** disease

4. A population like that of the United States with an age structure of roughly equal numbers in each of the age groups can be predicted to
A grow rapidly over a 30-year-period and then stabilize.
B grow little for a generation and then grow rapidly.
C fall slowly and steadily over many decades.
D show slow and steady growth for some time into the future.

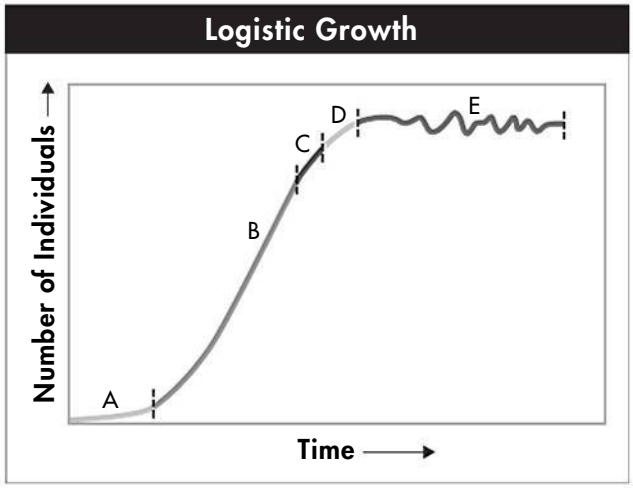
5. In the presence of unlimited resources and in the absence of disease and predation, what would probably happen to a bacterial population?
A logistic growth **C** endangerment
B exponential growth **D** extinction

6. Which of the following statements best describes human population growth?
A The growth rate has remained constant over time.
B Growth continues to increase at the same rate.
C Growth has been exponential in the last few hundred years.
D Birthrate equals death rate.

7. Which of the following refers to when a population's birthrate equals its death rate?
A limiting factor
B carrying capacity
C exponential growth
D population density

Questions 8–9

Use the graph below to answer the following questions.



8. Which time interval(s) in the graph shows exponential growth?
A D and E **C** C and D
B A and B **D** E only

9. Which time interval(s) in the graph depicts the effects of limiting factors on the population?
A A only **C** C, D, and E
B A and B **D** C and D

Open-Ended Response

10. When a nonnative species is imported into a new ecosystem, the population sometimes runs wild. Explain why this might be the case.

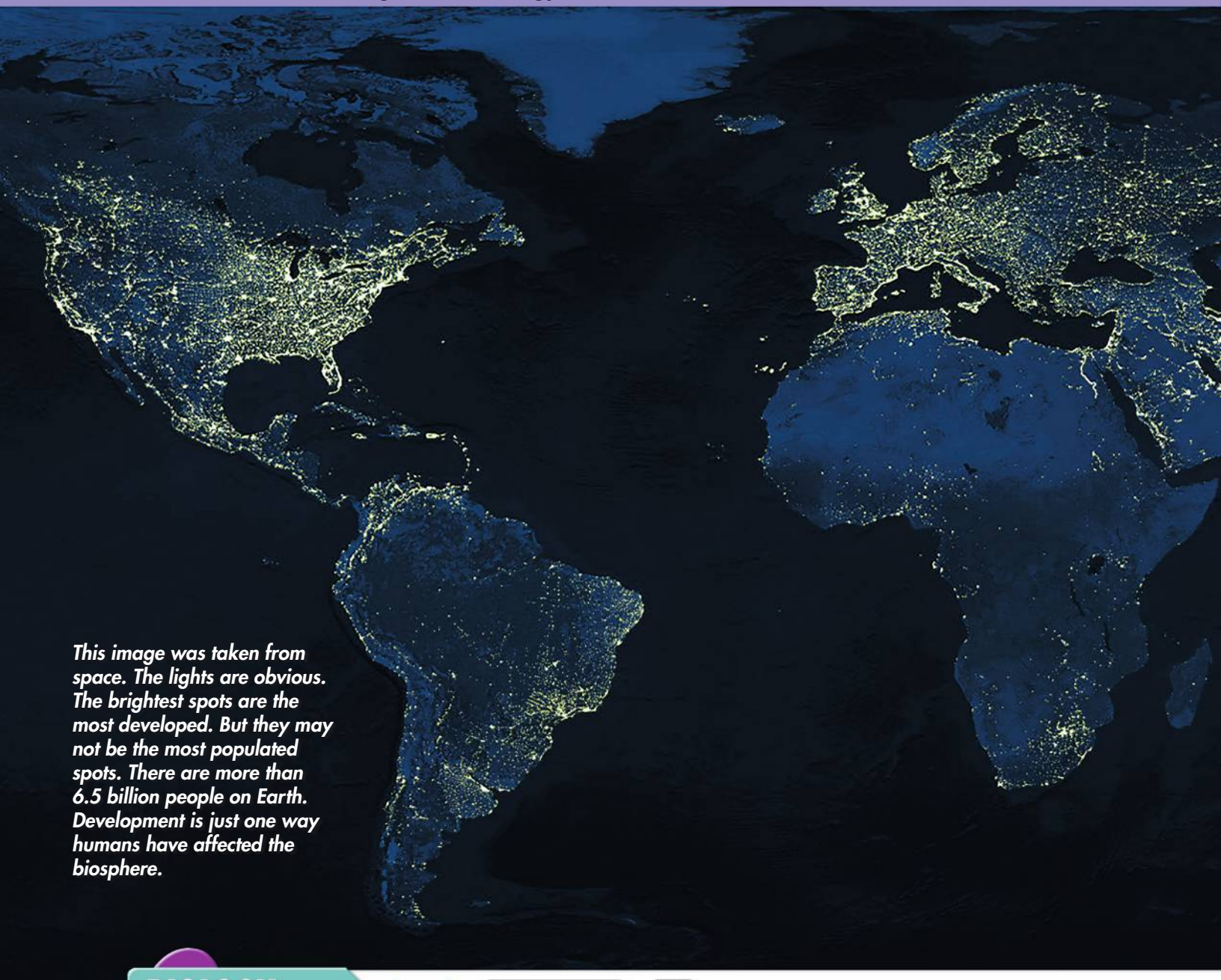
If You Have Trouble With . . .										
Question	1	2	3	4	5	6	7	8	9	10
See Lesson	5.1	5.1	5.2	5.3	5.1	5.3	5.1	5.1	5.2	5.2

6 Humans in the Biosphere

Big idea

Interdependence in Nature

Q: How have human activities shaped local and global ecology?



This image was taken from space. The lights are obvious. The brightest spots are the most developed. But they may not be the most populated spots. There are more than 6.5 billion people on Earth. Development is just one way humans have affected the biosphere.

BIOLOGY.com Search Chapter 6 GO • Flash Cards

INSIDE:

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

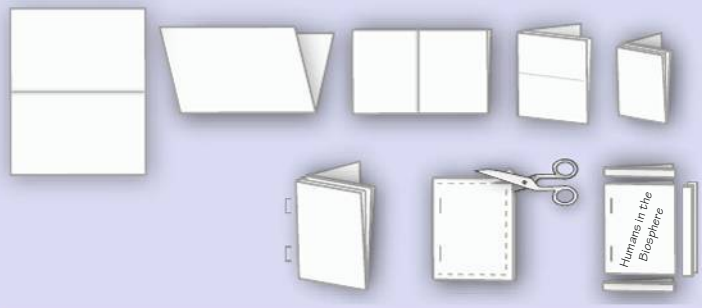
MOVING THE *MOAI*

Easter Island is a tiny island off the coast of Chile. The original islanders came from Polynesia. They called themselves Rapa Nui. They carved hundreds of huge stone statues called *moai* (MOH eye). Each statue weighs between 10 and 14 tons. About 800 years ago, the Rapa Nui moved the huge stones from quarries to places all around the island. Nearly all theories about this process suggest that strong, large logs were needed to move the *moai*. Yet, by the time Europeans landed on the island in 1722, there was no sign of any trees large enough to provide such logs. What had happened?

Read for Mystery Clues As you read this chapter, look for clues about the interactions of the Rapa Nui with their island environment. Then solve the mystery at the end of the chapter.

FOUNDATIONS for Learning

Before you read this chapter, make a mini book. Fold two pieces of notebook paper in half and then in half again in the other direction. Staple along the longer folded edge. This edge will be the spine of your book. Cut the folds along the folded edge. You should now have sixteen pages. Write the title of the chapter on the front cover of your mini book and each of the key questions within the chapter at the top of its own page. As you read the chapter, answer each key question in your own words. Use the remaining pages for additional notes.



6.1 A Changing Landscape

Key Questions

How do our daily activities affect the environment?

What is the relationship between resource use and sustainable development?

BUILD Understanding

Lesson Preview Before you read this lesson, write down the headings and look at the figures. Write one or two sentences about what topics you think will be covered. As you read, write the main idea under each heading.

In Your Workbook Go to your workbook to identify the main ideas of this lesson.

The Effect of Human Activity

People from Polynesia began to settle in Hawaii around 1600 years ago. These island people had customs that protected the natural resources. They did not catch fish during spawning season. If they cut down a coconut tree, they planted two trees to replace it. These settlers changed their environment. But they managed their islands carefully. Local ecosystems provided enough fresh water, fertile soil, fish, and other needs to support the population.

Europeans began moving to Hawaii in the late 1700s. These new settlers didn't understand the limits of island ecosystems. They imported many plants and animals. They cleared forests to plant crops. They covered land with housing and tourist developments. What happened?

Living on Island Earth Humans, like all living things, depend on Earth's life-support systems. We also change the environment when we obtain food, get rid of wastes, and build homes. These changes are most obvious on islands, such as Hawaii. Because islands are small, they have limited resources. If local ecosystems cannot supply food and other basic needs, they must be brought in from far away. That's the situation in Hawaii today. Fresh water is getting scarce. Food must be brought in from thousands of miles away.

On large continents, there used to be plenty of space, food, and water. So most of us don't think of land, food, or water as limited resources. But human activity has now used or changed half of all land not covered by ice and snow. As our population reaches 7 billion, we may be getting close to Earth's carrying capacity. Earth begins to feel like a very large island. Humans affect the biosphere of Earth through agriculture, development, and industry.

The Lesson of Hawaii The picture on the left is of Kalalau Valley on Kauai. It looks almost untouched by humans. The picture on the right is of Waikiki Beach on Oahu. Human development is very visible.

Agriculture Agriculture has been vital to human history. Once people could grow a dependable supply of food, they could gather together and live in towns and cities. Living in these large groups encouraged the growth of civilization.

Farmers have been able to double the world's food production over the last 50 years. One way they did this is through monoculture. **Monoculture** is the practice of clearing a lot of land to plant a single crop year after year. Farmers use machines to efficiently sow, tend, and harvest the crops. This is how farmers have supplied food for nearly 7 billion people. But monoculture can pollute soil and water. Also, running farm machinery and producing fertilizer both use a lot of fossil fuels.

Development In modern times, small settlements grew into crowded cities. Suburbs then grew out from those cities. All those dense human communities produce lots of wastes. If wastes are not treated properly, they can pollute the land, air, and water resources. Also, spreading development uses up farmland and divides natural habitats into fragments.

Industrial Growth The Industrial Revolution of the 1800s changed human society. Industry and science have led to many modern conveniences. We have comfortable homes and clothing and many electrical devices for work and play. It takes a lot of energy to produce and power these modern conveniences. We get most of this energy by burning fossil fuels—coal, oil, and natural gas. Also, industries have often gotten rid of wastes by dumping them into the air, water, and soil. All these activities can harm the environment.

Key Question How do our daily activities affect the environment?

People affect the environment through agriculture, development, and industrial growth. These activities affect the quality of Earth's natural resources, including soil, water, and the atmosphere.

BUILD Vocabulary

monoculture
a farming strategy of planting a single, highly productive crop, year after year

PREFIXES

The prefix *mono-* in monoculture means "one, alone, single." Monoculture is the practice of planting a single productive crop, year after year.

Monoculture Soybean fields dominate this landscape.

INQUIRY into Scientific Thinking

GUIDED INQUIRY

Reduce, Reuse, Recycle

Each person on Earth affects the biosphere. The garbage you throw out each day is one way you affect the biosphere. In this activity, you will find out how much you throw away in one day.

1. Get three containers to hold your trash for one day. Label the containers Reuse, Recycle, and Trash.
2. Throughout the day, collect your dry garbage.
3. Sort the garbage into the three containers. Items that cannot be reused or recycled will go into the Trash container. Be sure to wash your hands.

Analyze and Conclude

1. Analyze Data Compare the amount of garbage in each of your containers. About what percentage of the total did you put into each container?

2. Predict What do you think happens to the things you throw out? Think of at least three ways that garbage can impact living things.

3. Evaluate List three ways you can reduce the amount of trash you throw out each day.

In Your Workbook Get more help for this activity in your workbook.

Sustainable Development

We depend on healthy ecosystems to provide natural resources such as clean air and water. We usually take clean air and water for granted. But if the environment cannot provide them, our cities and towns must spend money to provide them. For example, drinking water is often filtered by wetlands. Water then flows through streams and rivers and is stored in lakes. But if the water sources or wetlands are polluted or damaged, water quality may fall. When this happens, cities and towns must build and run expensive water treatment plants to provide safe drinking water.

Ecosystem Services Hopper Marsh is a wetland in Illinois. It was drained for farming in 1900. The smaller image shows the marshland after it was drained. In 2003, the area was restored. The larger image shows how it looks now.

Renewable and Nonrenewable Resources There are two main types of natural resources. A **renewable resource** can be made or replaced by a healthy ecosystem. A single southern white pine is a renewable resource. A new tree can grow in place of an old tree that dies or is cut down. But some resources are nonrenewable. A **nonrenewable resource** cannot be replaced in a reasonable amount of time. Fossil fuels are nonrenewable resources. They take millions of years to form. When we use up the fossil fuels that are already here, they are basically gone forever.

Sustainable Resource Use We can learn to use natural resources to meet our needs without causing long-term environmental damage. Using resources this way is called sustainable development. Sustainable development should cause no long-term harm to the soil, water, and climate. It should use as little energy and materials as possible. It must be able to withstand droughts, floods, and heat waves or cold snaps. Sustainable development must also work well enough to help people improve their standard of living.

Key Question What is the relationship between resource use and sustainable development?

Sustainable development uses natural resources to meet human needs without causing long-term damage to the environment.

BUILD Vocabulary

renewable resource
a resource that can be produced or replaced by healthy ecosystem functions

nonrenewable resource
a resource that cannot be replenished by natural processes within a reasonable amount of time

RELATED WORD FORMS

The word *renew* is used to mean "to extend the checkout time for a library book" and "to begin again." These uses are related to renewable resources and nonrenewable resources. Renewable resources can be used over and over again. Nonrenewable resources cannot.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. When farmers plant the same crop in a field year after year, they are practicing _____.
2. Coal, oil, and natural gas are examples of _____ because they cannot be replaced in a reasonable amount of time.

Critical Thinking

3. **Relate Cause and Effect** How might practices that allow farmers to grow more crops affect a developing nation's population? How might the practices affect the nation's environmental health?
4. **Compare and Contrast** Explain why energy from the sun is a renewable resource but energy from oil is a nonrenewable resource.
5. **Apply Concepts** Imagine that a large shopping center is being built near your school. Until now, the land was basically untouched. There was a clump of trees and a large grassy field. How might the shopping center affect your local ecosystem?
6. **Write to Learn** Answer the first clue of the mystery. Keep in mind what can happen when an organism is introduced to a new environment.

MYSTERY CLUE

Easter Island's first colonists brought with them banana trees, taro root, and chickens. They may also have brought small mammals, such as rats. What impact might these new organisms have had on the island's ecosystems? (Hint: See p. 128.)

BIOLOGY.com Search Lesson 6.1 GO • Lesson Assessment

6.2 Using Resources Wisely

Key Questions

- ***Why is soil important, and how do we protect it?***
- ***What are the primary sources of water pollution?***
- ***What are the major forms of air pollution?***

BUILD Understanding

Concept Map As you read, make a concept map to organize the information in this lesson.

In Your Workbook Go to your workbook for help completing the concept map.

Soil Resources

Our economy is built on the use of natural resources. We cannot just stop using land for farming. Yet, we need to protect the health of ecosystems that supply us with renewable resources. How can we get what we need from local and global environments in a sustainable way?

You may not think of soil as a resource. Yet, many things you need depend on healthy soil. Food production depends on crops. Paper comes from trees. All these plants we rely on need healthy soil.

The mineral- and nutrient-rich portion of the soil is called topsoil. Good topsoil absorbs and holds the water that plants need but also allows some water to drain. It is rich in nutrients but low in salts. Topsoil can be renewable if it is managed well. Good topsoil is produced by many years of interactions between soil and plants. These processes take a long time to form good topsoil. But topsoil can be damaged or lost quickly. For example, large areas across the Great Plains in the United States were poorly farmed for years. Then, a very bad drought hit in the 1930s. The combination of bad farming and drought eroded topsoil. Crops failed. The area became like a desert. People began to call the Plains the "dust bowl." Thousands of people lost their homes and their jobs.

The Dust Bowl A ranch in Boise City, Idaho, is about to be hit by a cloud of dry soil on April 15, 1935.

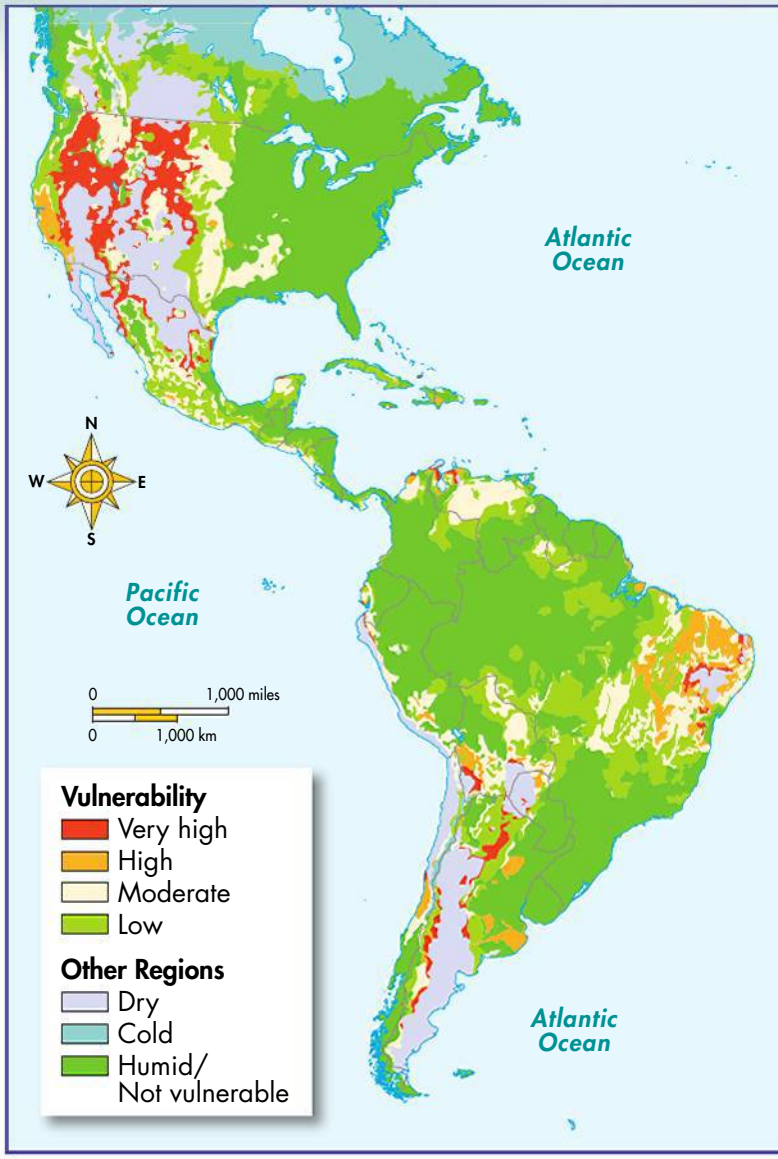
Soil Erosion The dust bowl was caused, in part, by the way the prairie was used as farmland. Soil erosion happens when wind or water take soil away. Soil erosion is often worse if land is plowed and left bare between plantings. Plant roots hold soil in place. If plants are taken out of the soil, then the soil is easily washed away. Sometimes, farming, overgrazing, and very little rain can turn farmland into desert. This is what happened in the Great Plains in the 1930s. The process is called **desertification.** About 40 percent of Earth's land is thought to be at risk for desertification.

The loss of forests, called **deforestation,** can also harm soils. Unfortunately, more than half of the world's old-growth forests have already been lost. Old-growth forests are forests that have never been cut. Deforestation can lead to severe soil erosion. Soils and microclimates can change so much that trees cannot grow there again. For example, topsoil in tropical rain forests is usually thin and not very fertile. The soil is often useful for only a few years after the forest is cut down.

Soil Use and Sustainability Soil is most likely to erode when it is completely bare. Leaving stems and roots in the soil between plantings can help hold soil in place. Also, different plants use different nutrients from the soil. When farmers plant different crops at different times of the year or in different years, it is called crop rotation. Crop rotation can help stop erosion and the loss of nutrients.

Another way to limit soil erosion is by contour plowing. Contour plowing is the practice of planting crops across the slope of the land instead of down the slope. This method reduces water runoff and erosion.

What are options for sustainable forestry? Cutting down only some of the mature trees within a forest can allow growth of younger trees without damaging the whole forest or its soil. Tree farms can also protect soil and make the trees themselves a renewable resource.



Desertification Risk The U.S. Department of Agriculture identifies the risk of desertification. The risk is based on soil type and climate.

Key Question Why is soil important, and how do we protect it?

Soil allows plants, including crops, to grow. Farming practices such as crop rotation and leaving stems and roots in the soil between plantings can help protect soil from erosion and a loss of nutrients. Cutting only some mature trees and using tree farms can also protect soil.

Freshwater Resources

Fresh water is usually considered a renewable resource. However, some sources of fresh water are not renewable. The Ogallala aquifer runs under eight states from South Dakota to Texas. It took more than a million years to fill. Today, more water is being pumped out than is returning through rain. The aquifer is likely to run dry in 20 to 40 years.

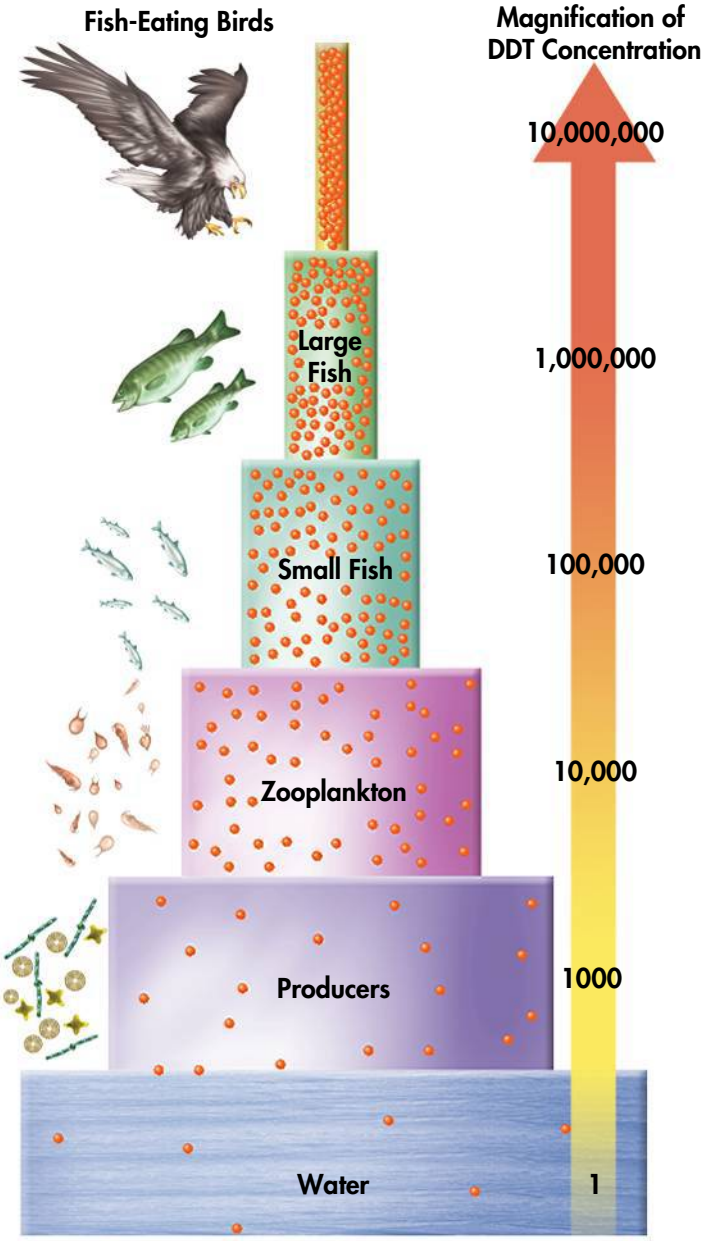
In many parts of the world, the amount of fresh water is limited. Only 3 percent of the water on Earth is fresh water. We must be careful to protect the ecosystems that collect and purify fresh water.

BUILD Vocabulary

desertification
lower land productivity caused by overfarming, overgrazing, seasonal drought, and climate change

deforestation
the destruction of forests

PREFIXES
The prefix *de-* in deforestation means "remove" or "away from." Deforestation is the removal of forests.



Water Pollution Freshwater sources can be affected by different kinds of pollution. A pollutant is any harmful material that can enter land, water, or air. When a pollutant enters water supplies from one spot, the source is called a point source. A factory or an oil spill are examples of point sources. When pollutants enter from many smaller sources, the sources are called nonpoint sources. Grease and oil washed off of roads are from nonpoint sources. Chemicals released into the air by factories and cars are also nonpoint sources.

▶ ***Industrial and Agricultural Chemicals*** Sometimes, a pollutant remains in the ecosystem for a long time. PCBs are a group of chemicals that were used in industry until the 1970s. These chemicals can still be found in parts of the Great Lakes and some coastal areas. Heavy metals like lead and mercury are also industrial pollutants.

Monoculture has increased the use of pesticides and insecticides. These chemicals can enter the water supply. Pesticides can be very dangerous pollutants. For example, DDT is a cheap, long-lasting type of pesticide that controls agricultural pests and mosquitoes. But when DDT gets into rivers and lakes, it can have serious effects.

These effects are caused by a process called **biological magnification.** Biological magnification begins when a pollutant is picked up by a primary producer, such as plants or algae. If the pollutant is not broken down, it stays in the plant tissues. Then, herbivores eat the plants. If the herbivores do not break down the pollutant, it gets concentrated in their tissues. When carnivores eat the herbivores, the compound is concentrated even more. Pollutant concentration keeps getting higher as the pollutant gets passed along the food chain. In the highest trophic levels, a pollutant may reach 10 million times its original concentration in the water.

High concentrations of pollutants can cause serious problems for wildlife and humans. High DDT concentrations in pelicans, falcons, and eagles caused these birds to lay eggs with thin, fragile shells. These eggs often didn't hatch, so the populations of these birds dropped.

BUILD Connections

BIOLOGICAL MAGNIFICATION

In the process of biological magnification, a pollutant like DDT—represented by the orange dots—becomes more concentrated as it passes up the food chain from producers to consumers.

In Your Workbook Do you understand how the concentration of a pollutant changes in the food web? Go to your workbook to find out.

Drip Irrigation One way to protect water supplies is to use less water. These cabbages are supplied water directly through drip irrigation. Tiny holes in water hoses allow farmers to deliver water only where it is needed.

▶ ***Sewage*** Have you ever stopped to think what happens after you flush your toilet? After you flush, the wastes become sewage. Sewage carries a lot of nitrogen and phosphorus. Healthy ecosystems can deal with some amount of these nutrients. However, large amounts of sewage can cause many bacteria and algae to grow. These organisms use up the water's oxygen. This depletion of the oxygen causes places called "dead zones." Other organisms are not likely to survive in dead zones. Sewage also carries tiny organisms that can spread disease.

Water Quality and Sustainability One way to make sure we have enough water is to protect ecosystems involved in the water cycle. For example, plants and forests around a water supply help to absorb excess nutrients and filter out pollutants. We must protect the land containing these plants. The land whose groundwater, streams, and rivers drain into the same body of water is called a watershed. In order to clean up a body of water, you must protect the whole watershed.

Cutting pollution rates can improve the water quality in a watershed. Sewage treatment can help prevent dead zones. In place of chemicals, farmers can sometimes use predators and parasites to keep insect populations small. Farmers may also use less-poisonous sprays and crop rotation.

Using less water is also important. One way to use less water in agriculture is to water the crops by drip irrigation. In drip irrigation, water is given directly to the roots of the plants that need it.

Key Question What are the primary sources of water pollution?
The primary sources of water pollution are industrial and agricultural chemicals, residential sewage, and nonpoint sources.

BUILD Vocabulary

biological magnification
the increasing concentration of a harmful substance in organisms at higher trophic levels in a food chain or food web

RELATED WORD FORMS

To magnify means "to increase the apparent or actual size of an object." In this context, the noun *magnification* refers to the increased concentration of a pollutant in organisms that are at higher levels of the food chain.

Smog The 2008 Summer Olympics were held in Beijing, China. For many weeks before the games, factories were closed and fewer cars were allowed on the streets. Yet Beijing remained under a blanket of dense smog.

Atmospheric Resources

The atmosphere has a direct effect on health. The atmosphere gives us the oxygen we need to breathe. The upper atmosphere contains a form of oxygen called ozone. Ozone protects us from the sun's ultraviolet radiation. The atmosphere also contains other gases such as carbon dioxide, methane, and water vapor. These gases are called greenhouse gases. Greenhouse gases help keep the Earth's temperature stable.

The atmosphere cannot be "used up." So, it is not important to call it renewable or nonrenewable. Instead, it is important to understand what human activities do to it.

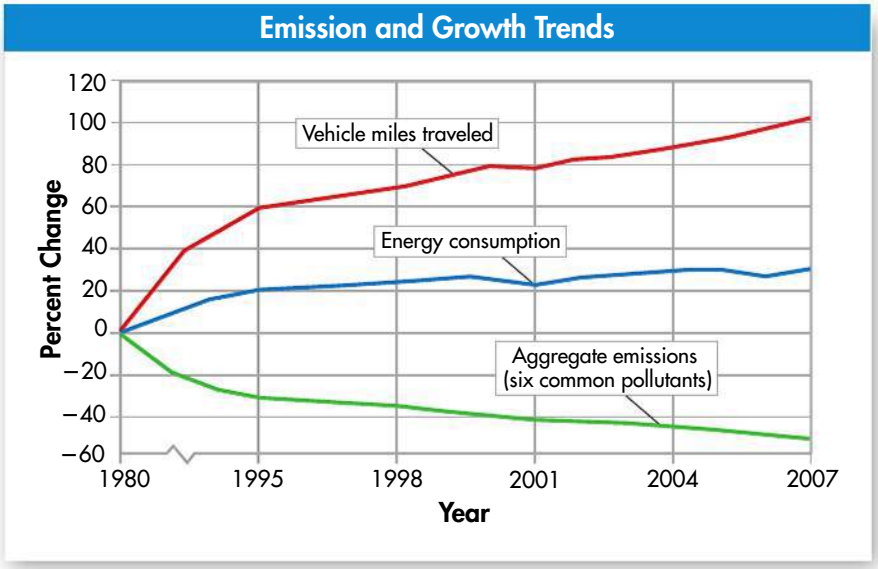
Air Pollution Many things, including the burning of fossil fuels, can cause air pollution. Some forms of air pollution are smog, acid rain, greenhouse gases, and particulates. When air is not clean, it can be hard to breathe. People who suffer from asthma and allergies will notice this effect the most. Certain types of air pollution can also cause global climate change.

▶ ***Smog*** If you have been to a large city, then you have probably seen smog. Smog is a gray-brown haze in the air. It is formed by chemical reactions among air pollutants. These reactions form ozone. High in the atmosphere, ozone protects life on Earth. Near ground level, ozone is dangerous, especially to people with difficulty breathing. In the 2008 Summer Olympics, many athletes were concerned about the level of smog in the air.

▶ ***Acid Rain*** Burning fossil fuels releases chemicals that combine with water vapor in the air to form acids. When the acids fall as rain, it is called acid rain. In some areas, acid rain damages leaves and changes the chemistry of soil and surface water. It can release toxic elements from soil, allowing them to move through the biosphere.

▶ ***Greenhouse Gases*** When we burn forests and fossil fuels, we release carbon dioxide into the atmosphere. Many kinds of farming release methane into the air. Natural concentrations of these greenhouse gases in the atmosphere control Earth's temperature. But by raising greenhouse gas concentrations, human activity plays a role in causing global warming and climate change.

▶ ***Particulates*** Particulates are tiny pieces of ash and dust. These are released by some industrial processes and by some diesel engines. Very small particulates can cause serious health problems when they enter the lungs.



Air Pollution Trends This graph summarizes findings of the United States Environmental Protection Agency (EPA). It shows the total percent change from 1980–2007 for energy consumption, vehicle mileage, and the combined concentration of six common pollutants—carbon monoxide, lead, nitrogen oxides, organic compounds, particulates, and sulfur dioxide.

Air Quality and Sustainability It is hard to clean up the air. Air doesn't stay in one place and doesn't "belong" to anyone. But many countries have made rules about car and truck emissions. These efforts are improving the air quality around the world. At one time, all gasoline had the metal lead in it. Car and truck exhaust carried lead into the air. Lead from the air washed onto land and into rivers and streams. The United States banned lead in gasoline in 1996. Now the lead levels in soils, rivers, and streams are much lower than they used to be.

Key Question What are the major forms of air pollution?
Common forms of air pollution include smog, acid rain, greenhouse gases, and particulates.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. When a forest is cleared so that farmers can plant crops, the process is called _____.
2. Pollutant concentrations may be much higher in consumers than in producers because of _____.

Critical Thinking

3. **Explain** Why is it important to protect soil resources?
4. **Apply Concepts** How can sewage affect a water source?
5. **Interpret Graphs** Look at the "Emission and Growth Trends" graph above. Describe the trends in emissions since 1980. Is this trend expected based on the rest of the data shown in the graph? Explain your answer.
6. **Write to Learn** Answer the second clue of the mystery. Before you answer, reread the introduction to the chapter mystery.

MYSTERY CLUE

Forests of palm trees with strong, tall trunks and edible seeds once covered most of Easter Island. Why would the islanders have cut down these forests? What effect would deforestation have had? (Hint: See page 133.)

BIOLOGY.com Search Lesson 6.2 GO • Lesson Assessment

6.3 Biodiversity

Key Questions

- ***Why is biodiversity important?***
- ***What are the most significant threats to biodiversity?***
- ***How do we preserve biodiversity?***

BUILD Understanding

T-Chart As you read the lesson, make a T-chart. In the left column, write the headings in the lesson. In the right column, write the main ideas from each heading.

In Your Workbook Go to your workbook to learn more about T-charts.

BUILD Vocabulary

biodiversity
the total of the variety of organisms in the biosphere; also called biological diversity

ACADEMIC WORDS

Variety and *variation* are nouns that refer to the differences among a group of things. Biodiversity is the total of all the different kinds of organisms, ecosystems, and genetic information in the biosphere.

The Value of Biodiversity

There are so many different kinds of living things on Earth. From deserts to pine forests, variety is "the spice of life." But variety gives us more than just interesting things to see. Our well-being is closely tied to the well-being of many other organisms. **Biodiversity** is the total of all the genetically based variation in all organisms in the biosphere. What are the different types of biodiversity? What is the value of biodiversity to society?

Types of Biodiversity There are three levels of biodiversity: ecosystem diversity, species diversity, and genetic diversity. Ecosystem diversity means the many different kinds of ecosystems that exist in the biosphere. Many different habitats, communities, and ecological processes are important to biodiversity. Species diversity is the number of different species in the biosphere or in a particular place. Biologists have studied and named more than 1.8 million species. They think that there are at least 30 million that no one has discovered yet. Single-celled organisms make up most of the diversity. But new species of multicellular organisms, like the snake below, are also being found.

Genetic diversity can mean all the different forms of genetic information carried by one species or by all organisms on Earth. In many ways, genetic diversity is the most basic kind of biodiversity. Genetic diversity is also the hardest kind to see and appreciate. If a population loses genetic diversity, it is less likely to be able to survive changes in its environment.

A New Species This tiny snake is native to the island of Barbados. It is one of many species that has been discovered recently. Photos of the snake were released in 2008.

Valuing Biodiversity Biodiversity is one of Earth's greatest natural resources. Biodiversity is very important in medicine and agriculture. Healthy and diverse ecosystems are important for soil, water, and air quality. Because you can't touch, taste, or smell biodiversity, it is easy to forget its value. But when biodiversity is lost, the biosphere and humanity may face serious consequences.

▶ ***Biodiversity and Medicine*** Many medicines are based on substances in wild species. Aspirin and penicillin were first made using wild species. The chemicals in wild species are used to treat depression and cancer. These chemicals are put together based on directions found in genes. When we lose biodiversity, we lose genetic information that may have been useful in medicine.

▶ ***Biodiversity and Agriculture*** Genetic diversity is also important in agriculture. Most crop plants have wild relatives. These wild plants may carry genes for such important features as disease resistance and pest resistance. If we lose the wild plants, we may lose those genes.

▶ ***Biodiversity and Healthy Ecosystems*** The number and variety of species in an ecosystem can affect the ecosystem's health. The loss of species may make an ecosystem less valuable to people. Sometimes changes in the population of a single species can change the whole ecosystem. Such important species are often called keystone species. Also, healthy and diverse ecosystems are important for soil, water, and air quality.

Key Question Why is biodiversity important?
Biodiversity is important in medicine and agriculture. Also, healthy and diverse ecosystems are important for soil, water, and air quality.

Potato Diversity The genetic diversity of wild potatoes in South America can be seen in the colorful varieties shown here. The International Potato Center in Peru houses a "library" of more than 4500 tuber varieties.

Keystone Species The sea otter is a keystone species. Sea otters eat sea urchins. Sea urchins eat kelp. When the otter population falls, the sea urchin population goes up. When the sea urchin population goes up, the kelp population drops.

Medicinal Plants Compounds in this foxglove plant are used to make medicine to treat heart disease.

BUILD Vocabulary

habitat fragmentation the splitting of ecosystems into pieces

ACADEMIC WORD

The noun *fragment* means "a broken or incomplete part." Habitat fragmentation forms broken and incomplete parts of an ecosystem.

Threats to Biodiversity

Species have been changing and dying out since life began. In fact, scientists think that over 99 percent of the species that have ever lived are now extinct. So extinction is not new. But human activity today is causing the greatest wave of extinctions since the dinosaurs died off. Scientists compare this loss of biodiversity to destroying a library before its books are read.

People reduce biodiversity by changing habitats, hunting, and introducing species into new places. Pollution and climate change also lower biodiversity.

Altered Habitats Often, people change a natural habitat into farmland or land for housing. When this happens, the number of species living nearby will go down. Some species may even become extinct. A species can be at risk even if a habitat is not completely destroyed. Development often breaks a habitat into smaller pieces. This process is called **habitat fragmentation.** This fragmentation leaves little habitat "islands." Competition for food, space, and other resources is very high. Some organisms are forced to leave. Others do not survive.

Hunting and the Demand for Wildlife Products People can push species to extinction by hunting them. In the 1800s, hunting wiped out the Carolina parakeet and the passenger pigeon. Endangered species in the United States are now protected from hunting. But hunting still threatens rare animals in Africa, South America, and Southeast Asia. Some animals are hunted for meat. Others are hunted for their hides or skins. Sometimes, animals are hunted to be sold as pets. Habitat fragmentation is very hard on hunted animals. Fragmentation leaves the hunted animals with fewer hiding places.

Habitat Fragmentation Housing developments in Florida have formed the pattern of forest "islands" shown here. Habitat fragmentation limits biodiversity and the potential size of populations.

Introduced Species In Chapter 5, you read about rabbits in Australia and about hydrilla plants in Florida. When a species is put into a new environment, its population can grow very quickly. The new species may out-compete native plants and animals. When this happens, the new species is called invasive.

Pollution Many pollutants can also lower biodiversity. For example, DDT prevents birds from laying healthy eggs. In the United States, many bird populations decreased because of DDT. Acid rain can hurt plants and animals on land and in the water. The increased carbon dioxide in the air is dissolving in oceans. The dissolved carbon dioxide makes the oceans more acidic. This increased acidity threatens the biodiversity on coral reefs and in other ocean ecosystems.

Climate Change A change in climate can be a major threat to biodiversity. Species are adapted to their environment. A species may survive only within a certain temperature range. Species also need a certain amount of rain. If temperatures or rainfall change, organisms may need to move to survive. Species in fragmented habitats are even more affected by climate change. If global temperatures rise as much as many researchers predict, many species will become extinct.

Key Question What are the most significant threats to biodiversity?

Biodiversity is threatened by changing habitats, hunting, and introduced species. Pollution and climate change also threaten biodiversity.

Conserving Biodiversity

What can we do to protect biodiversity? Should we focus on one species? Should we try to save an entire ecosystem? We need to do both. We also need to consider human needs and interests.

Protecting Individual Species The Association of Zoos and Aquariums (AZA) tries to protect organisms, one species at a time. A key part of their plans is a captive breeding program. Members of the AZA choose and manage mating pairs. They are trying to increase genetic diversity. The goal is to return the organisms to the wild. The AZA is currently trying to protect more than 180 species. The giant panda is one of these species.

Preserving Habitats and Ecosystems Scientists are not only trying to save individual species. Now, they have begun to focus on protecting entire ecosystems. This can help many species at once. Governments and conservation groups work to set aside land for parks and reserves. The United States has national parks, forests, and other protected areas.

Saving an Individual Species A number of efforts are being made to save the giant panda. These efforts include captive breeding and reintroduction programs. Here, a specialist from China holds one of twin pandas born at a zoo in Madrid, Spain.

Ecotourism A tourist gets an elephant-size kiss from one of the rescued elephants at Thailand's Elephant Nature Park. This kind of park helps protect biodiversity and brings tourist dollars to the area.

Biologists face the challenge of finding the best areas to protect. They have identified ecological hot spots to make sure conservation efforts happen in places where they are most needed. An ecological hot spot is a place where many species and habitats are in immediate danger of extinction. Biologists hope that identifying these spots will help them focus on the right places.

Considering Local Interests In order to protect biodiversity, people need to change their habits. Sometimes, they even need to change their jobs. In these cases, it is helpful to give money or other rewards in support for the changes. In the United States, the government has given tax breaks to people who buy hybrid cars or who put solar panels on their houses. In Africa, Central America, and Southeast Asia, countries have set aside land for parks and nature reserves.

Industries are also encouraged to change their habits. For example, companies may be rewarded for releasing less carbon into the environment. These examples show that conservation efforts work best when they are based on scientific information and when they benefit the affected community.

Key Question How do we preserve biodiversity?
To preserve biodiversity, we need to protect individual species as well as whole ecosystems. We also need to keep human interests and needs in mind.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

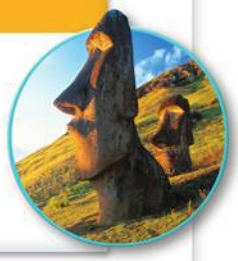
1. The number of different species in the biosphere or in a particular place is one level of _____.
2. The process of _____ often leaves small "islands" of space for animals and plants to live between more developed land.

Critical Thinking

3. **Apply Concepts** How are people helped by biodiversity?
4. **Relate Cause and Effect** What usually happens to the size and diversity of populations after development causes habitat fragmentation?
5. **Explain** Why is it important to consider local interests when finding ways to protect local ecosystems?
6. **Write to Learn** Answer the third clue in the mystery. In your answer, use the terms *introduced species* and *compete*.

MYSTERY CLUE

Almost all of the coconut shells on Easter Island show signs of having been gnawed on by rats, which are not native to the Island. Coconuts hold the seeds of the coconut palm tree. How do you think the rats affected the coconut palm population? (Hint: See p. 141.)



BIOLOGY.com Search Lesson 6.3 GO • Lesson Assessment

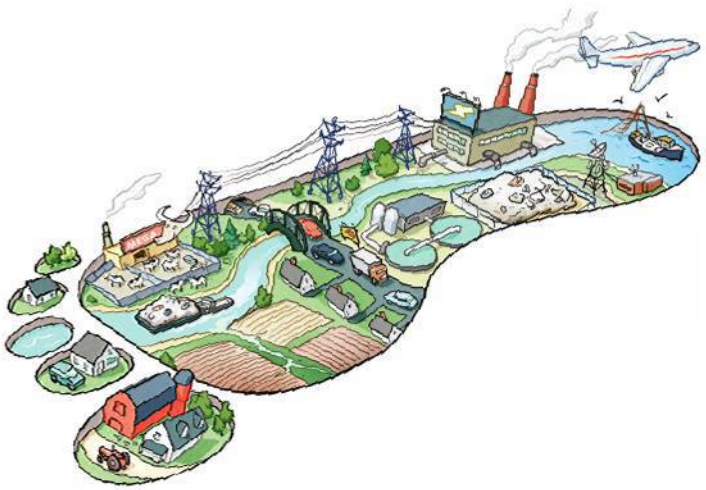
6.4 Meeting Ecological Challenges

Ecological Footprints

Every year, the United States Environmental Protection Agency (EPA) gives out up to ten Environmental Youth Awards. These awards are given to students with ideas that protect the environment in ways that meet the needs of local people. One winner encouraged people who fish to stop using lead weights. These weights put lead in the water. The lead can make the plants and animals that live in or drink the water sick. Another group of winners found ways to reduce waste at their school. Their program saved the school more than a million dollars. This kind of leadership will help us find a new direction for the future.

What is our impact on the biosphere? Think about the kind and amount of resources each of us uses. Ecologists use a concept called the ecological footprint. The **ecological footprint** describes the total area of the land and water ecosystems that provide the resources that each person uses. Ecological footprints include resources such as energy, food, water, and shelter. They also include the resources needed to absorb wastes such as sewage and greenhouse gases. An ecological footprint can be used to determine the carrying capacity for humans.

Footprint Limitations Ecologists talk about the ecological footprint of individuals, of countries, and of the world's population. It is difficult, if not impossible, to calculate an exact footprint. The idea is very new. There is not yet a standard way of measuring footprint size. Also, footprints give only a "snapshot" of the resources used at a particular point in time.



Key Questions

- ***How does the average ecological footprint in America compare to the world's average?***
- ***How can ecology guide us toward a sustainable future?***

BUILD Understanding

Compare/Contrast Table As you read, make a table comparing the challenges associated with the ozone layer, fisheries, and global climate. Note the problem observed, the causes identified, and the solutions implemented.

In Your Workbook Go to your workbook for help completing the compare/contrast table for Lesson 6.4.

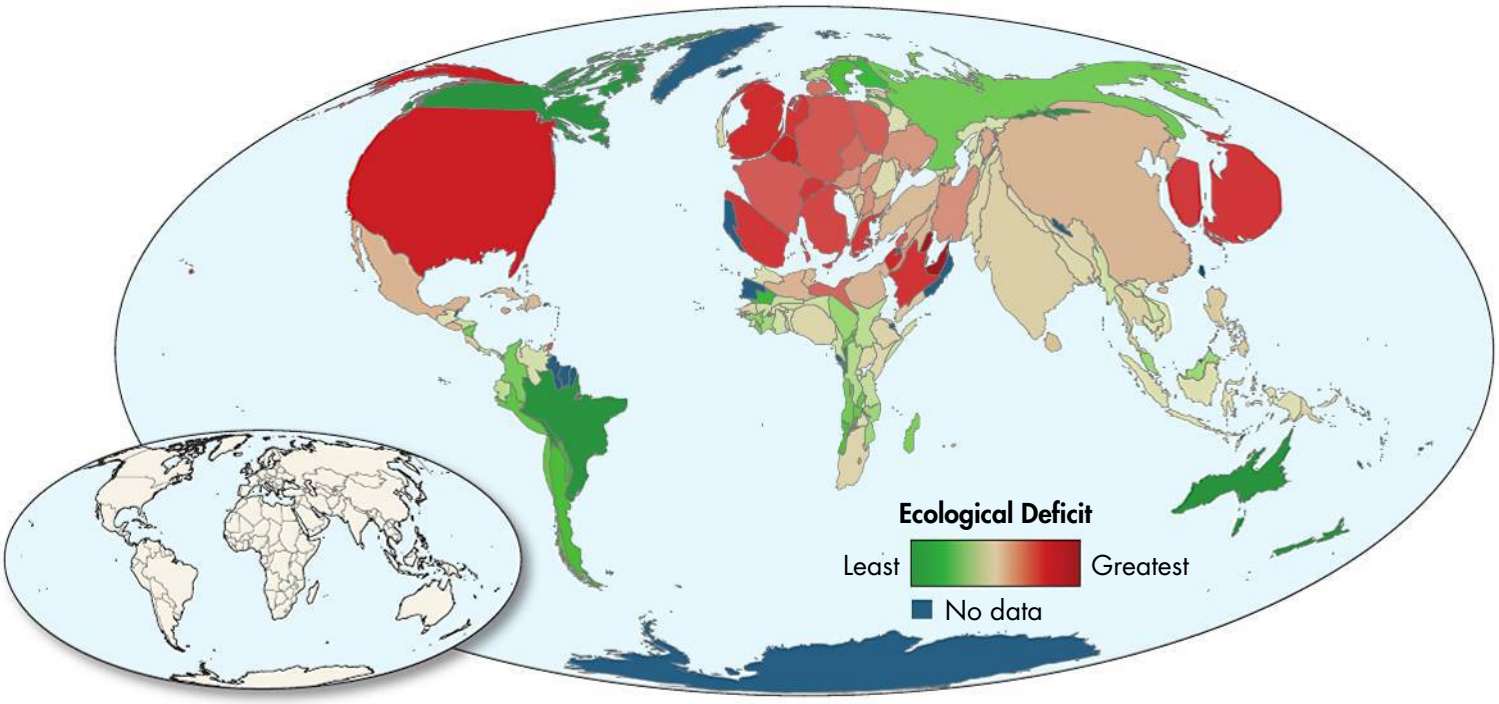
BUILD Connections

ECOLOGICAL FOOTPRINTS

The food you eat, the miles you travel, and the electricity you use all contribute to your—and the population's—ecological footprint.

In Your Workbook Do you understand the analogy of the ecological footprint? Go to your workbook for extra practice.

BIOLOGY.com Search Lesson 6.4 GO • Visual Analogy



Relative Footprint This world map shows each country in proportion to its ecological footprint. The average American has an ecological footprint more than four times the world's average. By contrast, the average person in the African nation of Zambia has a footprint a little over one fourth the global average. Compare each country's footprint size on the color map to its actual size on the smaller map.

Comparing Footprints Calculating an exact footprint is almost impossible. However, this idea can be very useful when comparing different populations. For example, each person in the United States uses more than four times as many resources as the worldwide average. On average, each person in the United States uses almost twice as many resources as someone in England. To calculate the ecological footprint of an entire country, researchers first calculate the footprint of an average citizen. Then they multiply that footprint by the population of the country.

Key Question How does the average ecological footprint in America compare to the world's average?
The average American has an ecological footprint of more than four times the global average.

BUILD Vocabulary

ecological footprint
the total amount of functioning ecosystem needed both to provide the resources a human population uses and to absorb the wastes that population generates

ozone layer
an atmospheric layer in which ozone gas is relatively concentrated; protects life on Earth from harmful ultraviolet rays in sunlight

WORD ORIGINS

The word *ozone* comes from the Greek word that means "to smell." Ozone gas smells a little like chlorine gas.

Ecology in Action

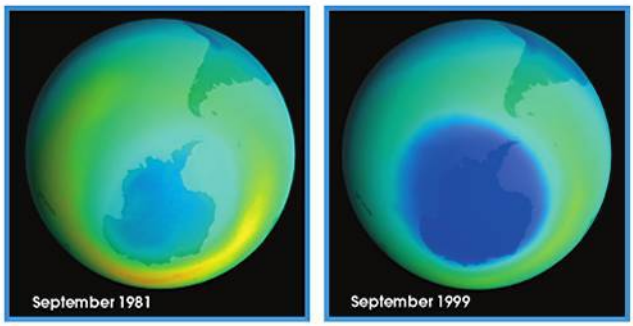
Our ecological footprints are very important to the future of the biosphere. Global population growth and technology are also important. We often hear more stories about ecological challenges than ecological successes. But good ecological research can make a difference. Ecologists follow three basic steps: (1) recognize the problem; (2) find the cause; (3) change behavior. Following these steps can lead us to a sustainable future.

Key Question How can ecology guide us toward a sustainable future?
By (1) recognizing the problem, (2) determining the cause, and (3) changing our behavior, we can make a difference.

Case Study #1: Atmospheric Ozone

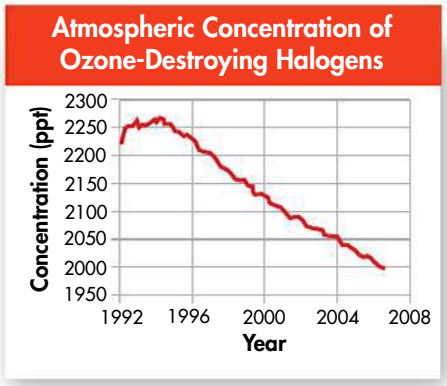
Near the ground, ozone is a pollutant. However, ozone forms an important layer high in the atmosphere. This layer is called the **ozone layer.** The ozone layer absorbs the ultraviolet (UV) rays from the sun. UV can cause sunburn and skin cancer. It also damages eyes and lowers resistance to disease. In extreme cases, UV can damage plants and algae. By absorbing UV light, the ozone layer is like a global suncreen.

The following is an ecological success story. Over four decades, society has recognized a problem, identified its cause, and cooperated internationally to address the global problem.



The Disappearing Ozone

CFC-Containing Refrigerators



The Decline of CFCs

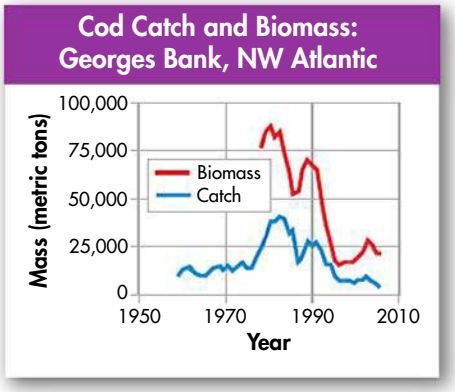
1 Recognizing a Problem: "Hole" in the Ozone Layer In the 1970s, scientists realized that the ozone concentration over Antarctica was dropping during the winter. The area was called an ozone hole. Of course, there was not a real hole in the atmosphere. There was less ozone. For several years, the ozone hole was getting bigger each year.

2 Researching the Cause: CFCs In 1974, research showed that gases called chlorofluorocarbons (CFCs) could hurt the ozone layer. CFCs had been used in spray cans, refrigerators, and air conditioners. They were also used to make plastic foams.

3 Changing Behavior: Regulation of CFCs Once the research was accepted by scientists, the rest was up to governments. There was a big response. Following the recommendations of ozone researchers, 191 countries agreed to ban most uses of CFCs. CFCs can stay in the atmosphere for a hundred years. So, the effects of CFCs on the ozone layer are still visible. But current data suggest that the ozone hole will "close" in the next fifty years.

Case Study #2: North Atlantic Fisheries

In 1950, fishermen around the world caught about 19 million tons of seafood. In 1997, fishermen caught more than 90 million tons. People thought that the fish supply was an endless, renewable resource. However, commercial fish populations are now dropping dramatically. This problem is one that society is still working on.



The Decline of Cod As the mass of the cod populations dropped, the catch also decreased.

Overfishing

Aquaculture

1 Recognizing a Problem: More Work, Fewer Fish The amount of cod caught rises and falls each year. Sometimes, these differences are because of natural differences in ocean ecosystems. Often, however, low fish catches happen when boats start taking too many fish. From the 1950s to the 1970s, fishermen began using larger boats and more high-tech equipment to find fish. At first, the fishermen caught more fish. Then the catches began falling again. The mass of cod in the ocean has decreased significantly since the 1980s. Fishermen cannot catch what isn't there.

2 Researching the Cause: Overfishing Ecologists gathered data including age structure and growth rates. Fish populations were getting smaller. By the 1990s, the cod populations had dropped so low that researchers were afraid the fish might disappear forever. It became clear that more fish were being caught than were being born.

3 Changing Behavior: Regulation of Fisheries The United States has set up rules for commercial fishing. These rules state how many fish of what size can be caught. Certain places have been closed to fishing until populations rise again. Other places are closed during breeding seasons. These rules are helping some populations but not all. Aquaculture, the farming of aquatic animals, can also help. It offers an option for commercial fishing.

Progress has been slow. Some countries are not setting up their own rules. Some countries are afraid that these rules take away jobs and income for fishermen. Scientists and lawmakers are still trying to find a solution. They are trying to find ways to protect the fish populations with as little negative impact on the industry as possible.

Case Study #3: Climate Change

Global climate is affected by the cycles of matter and everything that humans do. This includes cutting and burning forests, manufacturing, driving cars, and making electricity. The Intergovernmental Panel On Climate Change (IPCC) began in 1988. Its goal is to provide the best scientific information on climate change. The 2007 report from the IPCC gives the most reliable current information on climate change.

1 Recognizing the Problem: Global Warming The IPCC report states that global temperatures are rising. This rise in average temperature is called global warming. The report also covers climate change. Temperature, rain, and other factors can change because of global warming. Scientists studied physical and biological evidence of climate change.

- **Physical Evidence** Earth's temperatures are getting warmer, sea ice is melting, and sea levels are rising. Eleven of the twelve years between 1995 and 2006 were among the warmest years ever recorded. People began recording temperatures in 1850. Earth's average global temperature rose by 0.74°C between 1906 and 2005. The largest changes are taking place in and near the Arctic Circle. Alaska's average temperature rose 2.4°C in fifty years. Sea level has risen 1.8 mm each year since 1961. This rise is being caused by warmer water expanding and by melting glaciers, ice caps and polar sheets.

A Warming Earth

Change in Global Land-Surface Air Temperature, 1850–2005

Change in Mean Global Sea Ice, 1953–2007

Change in Global Sea Level, 1870–2005

• **Biological Evidence** Small changes in climate that people barely notice can be important to other organisms. Temperature, humidity, and rain affect where an organism can live. If temperatures rise, organisms need to move to cooler places. They may move away from the equator or higher up a mountainside. Plant flowering and animal breeding are also affected by rising temperatures. These organisms may respond as though spring were beginning earlier.

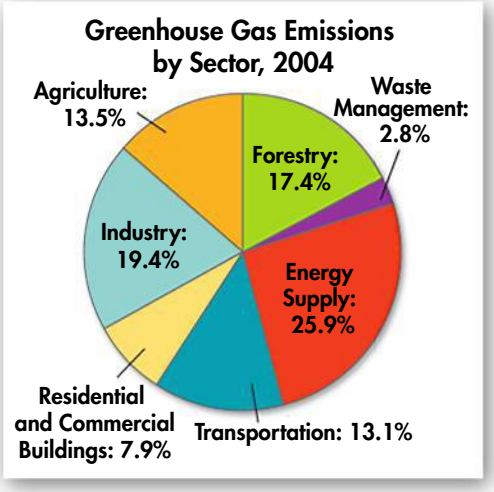
The IPCC report is based on 75 different studies. These studies covered 1700 species of plants and animals. Many species and communities are reacting to the rising temperatures.

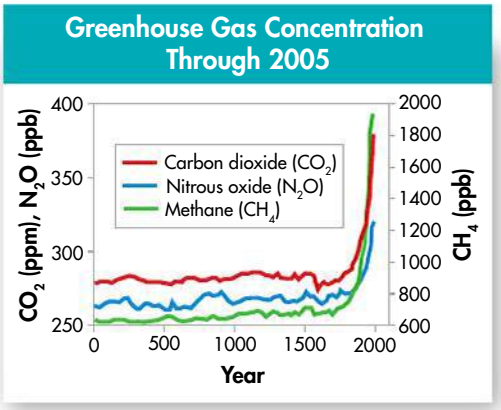
Biological Evidence This yellow-bellied marmot is coming out of hibernation over a month earlier than it used to.

2 Researching the Cause: Models and Questions Earth's climate has changed often during its history. Concentrations of carbon dioxide and several other greenhouse gases have risen over the last 200 years. People and their activities are adding more carbon dioxide to the atmosphere than the carbon cycle can remove. Most scientists around the world agree that this added carbon dioxide is increasing the greenhouse effect. In turn, the biosphere is holding more heat.

• **How Much Change?** How much are global temperatures expected to rise? Researchers use computer models based on climate data. The models are complex, and they make many assumptions. So, there is some debate about the predictions. Several models suggest that, by the end of this century, average temperatures may rise by as much as 6.4°C over the average in the year 2000.

• **Possible Effects of Climate Change** What does all of this mean? Some changes may damage ecosystems from tundra to the Amazon rain forest. The western United States is likely to get drier. But the Sahara Desert may become greener. Many places may flood because of rising sea levels. Other places in North America may face more droughts.

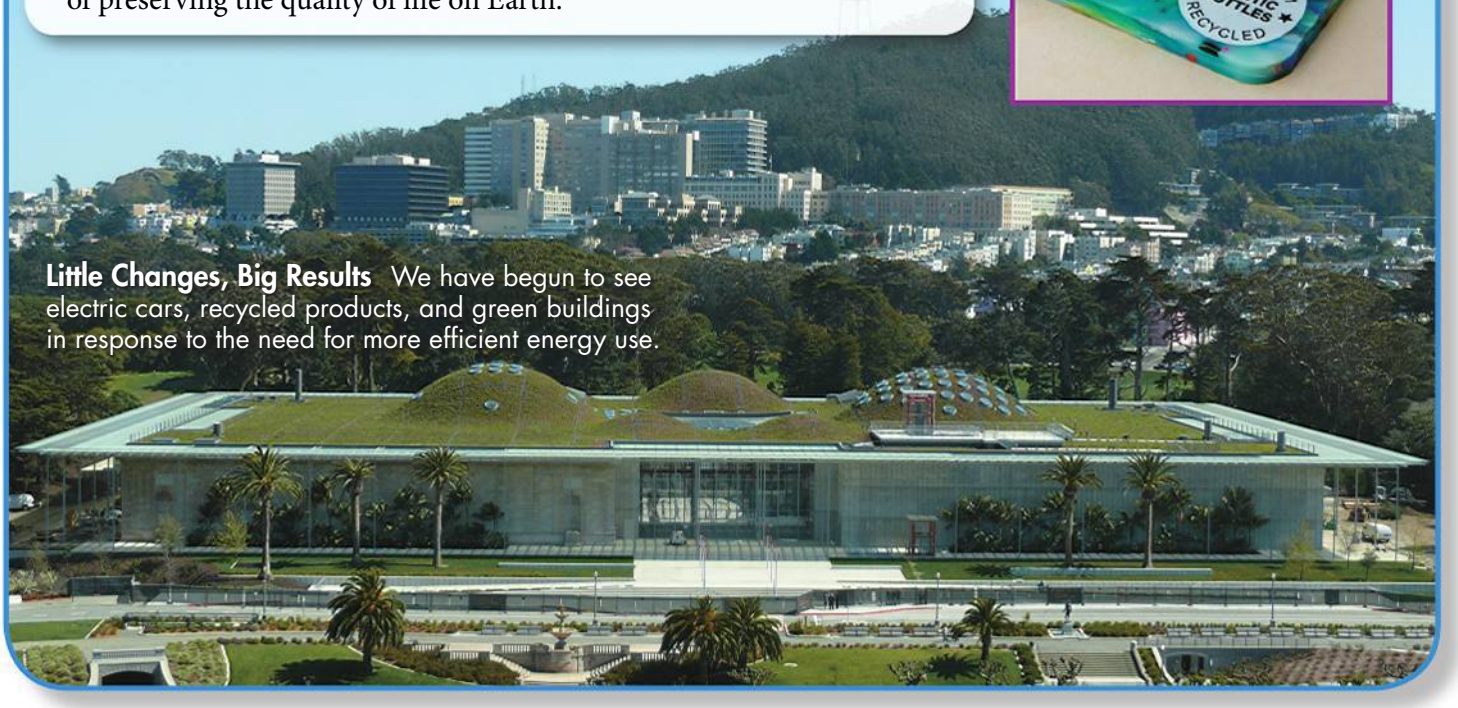




Case Study #3: Climate Change (*continued*)

3 Changing Behavior: The Challenges Ahead You have read how research has led to changes that are protecting the ozone layer and helping to bring back fish populations. Global climate change presents many challenges. The changes in behavior will need to be major. The changes will affect economies and many other fields besides biology. Some changes will depend on new technology for renewable energy and more efficient energy use.

Nations around the world have begun to work out agreements to protect the atmosphere and the climate. As the world and our nation work through these challenges, remember that the world is our island of life. Hopefully, there will come a day when we reach the common goal of preserving the quality of life on Earth.



Little Changes, Big Results We have begun to see electric cars, recycled products, and green buildings in response to the need for more efficient energy use.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. All of the energy you use, food you eat, and garbage you throw out contribute to your _____.
2. Beginning in the 1970s, scientists began to realize that the _____ over Antarctica was getting thinner.

Critical Thinking

3. **Apply Concepts** How is the concept of the ecological footprint limited? When is the concept most useful?
4. **Sequence** Describe the three steps ecologists can use to lead us toward a sustainable future.
5. **Write to Learn** Look back at the Warming Earth graphs on page 147. Describe what these graphs tell us about global climate change.

BIOLOGY.com Search Lesson 6.4 GO • Lesson Assessment

Design Your Own Lab

OPEN-ENDED INQUIRY

Pre-Lab: Acid Rain and Seeds

Problem How does acid rain affect seed germination?

Materials white vinegar, distilled water, large test tubes, test-tube rack, glass-marking pencil, 25-mL graduated cylinder, food coloring, pipette, pH paper, dried beans, paper towels, zip-close plastic bags, stick-on labels, hand lens, graph paper

Lab Manual Chapter 6 Lab

Skills Focus Design an Experiment, Organize Data, Measure, Graph

Connect to the Big idea Every organism alters its environment in some way. Elephants uproot trees, prairie dogs dig tunnels, and corals build reefs. But no other organism has as much impact on the global environment as humans. One of the ways that humans affect global ecology is by burning fossil fuels. The burning produces carbon dioxide, which can accumulate in the atmosphere and cause climate change. Other products react with water to form nitric and sulfuric acids. Rain that contains these acids can damage many things, including stone statues and growing plants. In this lab, you will investigate the effect of acid rain on seeds.

Background Questions

a. **Review** What does a pH scale measure?

b. **Review** Which solution is more acidic, one with a pH of 4.0 or one with a pH of 5.0, and why?

c. **Explain** Use the water cycle to trace the path from acids in water vapor to plants.

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Design an Experiment** What do you think the purpose is of adding food coloring to the vinegar in Part A?
2. **Infer** How will you know that a seed has germinated?
3. **Using Models** In this lab, what do the solutions represent?

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Visit Chapter 6 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video The Untamed Science crew visits a zoo to learn about the important work that goes on behind the scenes.

Art in Motion View a short animation of biological magnification.

Art Review Review your understanding of the various threats to biodiversity with this activity.

Visual Analogy Compare human impact on the biosphere to a footprint in this activity.

6 CHAPTER Summary

6.1 A Changing Landscape

- People affect the environment through agriculture, development, and industrial growth.
- Sustainable development uses natural resources to meet human needs without causing long-term damage to the environment.

monoculture (p. 129)
renewable resource (p. 131)
nonrenewable resource (p. 131)

6.2 Using Resources Wisely

- Soil allows plants, including crops, to grow. Farming practices such as crop rotation and leaving stems and roots in the soil between plantings can help protect soil from erosion and a loss of nutrients. Cutting only some mature trees and using tree farms can also protect soil.
- The primary sources of water pollution are industrial and agricultural chemicals, residential sewage, and nonpoint sources.
- Common forms of air pollution include smog, acid rain, greenhouse gases, and particulates.

desertification (p. 132)
deforestation (p. 133)
biological magnification (p. 134)

6.3 Biodiversity

- Biodiversity is important in medicine and agriculture. Also, healthy and diverse ecosystems are important for soil, water, and air quality.
- Biodiversity is threatened by changing habitats, hunting, and introduced species. Pollution and climate change also threaten biodiversity.
- To preserve biodiversity, we need to protect whole ecosystems as well as individual species. We also need to figure out how to preserve the environment while helping people improve their standard of living.

biodiversity (p. 138)
habitat fragmentation (p. 140)

6.4 Meeting Ecological Challenges

- The average American has an ecological footprint of more than four times the global average.
- By (1) recognizing a problem in the environment, (2) determining the cause, and (3) changing our behavior, we can move toward a sustainable future.

ecological footprint (p. 143)
ozone layer (p. 145)

6 CHECK Understanding

Assess the Big idea Interdependence in Nature

Write an answer to the question below.
Q: How have human activities shaped local and global ecology?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs long. To help you begin, read the **Hints** below each of the questions.

1. **Why does the concentration of pollutants, such as DDT, increase in higher levels of a food chain?**

   Hint When DDT is consumed by an organism, the body does not break it down.

   Hint Primary producers can pick up a pollutant directly from the environment.

2. **Describe the relationship between agriculture and soil quality.**

   Hint Soil erosion happens when wind or water takes soil away.

   Hint Topsoil is the mineral- and nutrient-rich portion of soil.

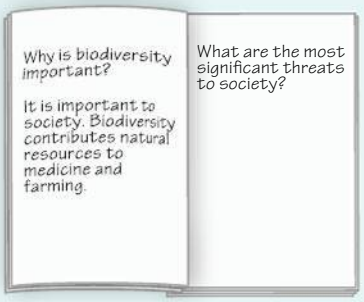
   Hint Topsoil can be a renewable resource, but it can be lost or damaged quickly.

Foundations for Learning Wrap-Up

Use the mini book you created before reading the chapter as a tool to help you organize your thoughts about humans in the biosphere.

Activity 1 Working with a partner, review your answers to the key questions. Did you both answer the questions correctly and completely? If not, work together to make any corrections.

Activity 2 Working in a small group, use your mini books to prepare a lecture on how human activities have shaped ecosystems. In your lecture, mention how your own activities shape local and global ecology. Present one idea about what you could do as a school to reduce your ecological footprint.



6.1 A Changing Landscape

Understand Key Concepts

1. A resource that can be replenished or replaced is called
   - **a.** common.
   - **b.** renewable.
   - **c.** nonrenewable.
   - **d.** recycled.

2. The concept of using natural resources to meet the needs of humans without causing long-term environmental damage is called
   - **a.** monoculture.
   - **b.** sustainable development.
   - **c.** recycling.
   - **d.** resource renewal.

Test-Taking Tip

Read All of the Answer Choices Take the time to read all of the answer choices carefully. Question 2 asks for the word or phrase that is defined in the question. Decide whether you know the definitions of the answer choices. Once you define all of the answer choices, you'll find that **b** is the correct answer. Sustainable development is the use of natural resources in an environmentally conscious way.

3. Describe how Hawaiian settlers negatively affected the islands after the 1700s.
4. Explain how Earth is like an island.

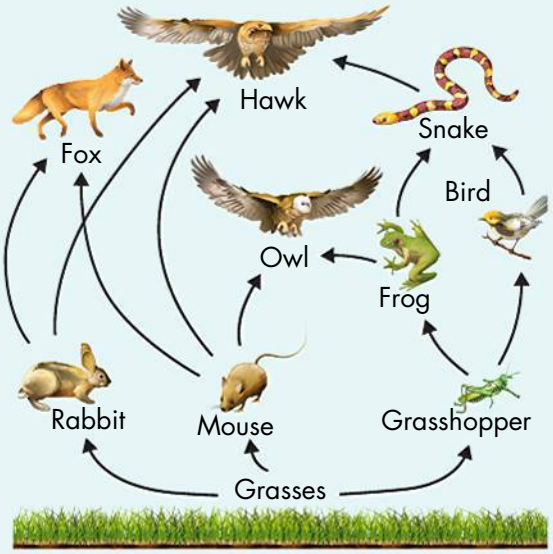
Think Critically

5. **Compare and Contrast** How are renewable resources and nonrenewable resources alike? How are they different?

6.2 Using Resources Wisely

6. The loss of topsoil through the action of water or wind is called
   - **a.** acid rain.
   - **b.** erosion.
   - **c.** desertification.
   - **d.** monoculture.

7. Look closely at the image of the food web shown below. In which organism would the concentration of a pesticide probably be highest?
   - **a.** hawk
   - **b.** rabbit
   - **c.** frog
   - **d.** grasses



8. How can forests be managed in a sustainable way?
9. What are some of the common sources of water pollution?

Think Critically

10. **Relate Cause and Effect** How does the use of fossil fuels negatively impact Earth's atmosphere?

6.3 Biodiversity

11. Which of the following is NOT a term for one of the three levels of biodiversity?
    - **a.** species diversity
    - **b.** population diversity
    - **c.** genetic diversity
    - **d.** ecosystem diversity

12. A place where many species and habitats are in immediate danger of extinction is called a(n)
    - **a.** altered habitat.
    - **b.** habitat fragment.
    - **c.** ecological hot spot.
    - **d.** dead zone.

13. What are the major threats to biodiversity?

Think Critically

14. **Compare and Contrast** Explain the difference between species diversity and ecosystem diversity.

6 CHECK Understanding

6.4 Meeting Ecological Challenges

Understand Key Concepts

15. The increase in the average temperature on Earth is called

a. global warming. **c.** atmospheric change.

b. climate change. **d.** Earth warming.

16. What are some of the biological effects of climate change?

Think Critically

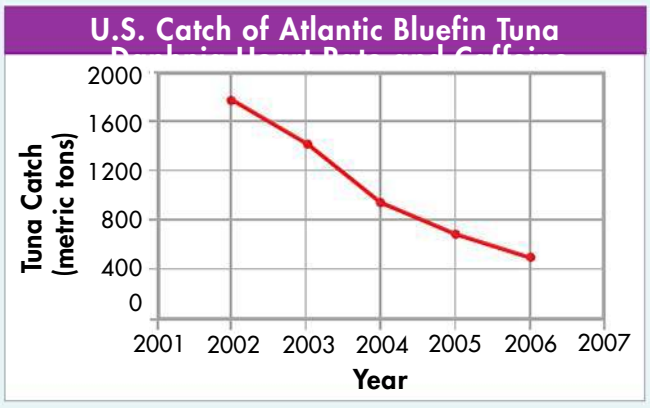
17. **Explain** How is the ozone layer important to living things?

18. **Apply Concepts** Describe some of the steps taken to solve the problem of overfishing cod in the North Atlantic.

Connecting Concepts

Use Science Graphics

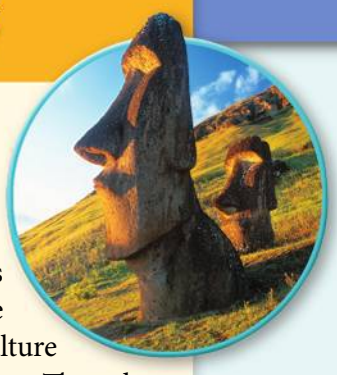
The graph shows the amount of bluefin tuna caught by the United States in the Atlantic Ocean between 2002 and 2006. Use the graphics to answer questions 19 and 20.



19. **Predict** What trend would you expect to see in the annual catch from 2006 to 2007?

20. **Propose a Solution** What recommendations would you make to help the bluefin tuna population recover in the next decade or two?

solve the CHAPTER MYSTERY



MOVING THE *MOAI*

Easter Island did not have as much biodiversity as the Hawaiian Islands. This made it less resistant to ecological damage. The Rapa Nui cut palm trees for agriculture and for wood to make fishing canoes. They also used large logs from palm trees to move *moai*. They cleared fields and did not protect the soil from erosion. Healthy topsoil washed away.

The Rapa Nui brought rats to the island. Rat populations grew exponentially. Hordes of hungry rats killed young palm trees. They ate coconuts and their seeds.

The combination of human activities and introduced species destroyed almost all of Easter Island's forests. Because of deforestation and the difficult climate, the island has been able to house very few people ever since.

1. **Relate Cause and Effect** Easter Island is about half the size of Long Island, New York. How did its small size affect the outcome of deforestation and the introduction of rats?

2. **Compare and Contrast** Gather information about the geography, climate, and biological diversity on the Hawaiian Islands and on Easter Island. How do you think the differences made the islands respond differently to human settlement?

UntamedScience **Never Stop Exploring Your World.** The mystery of Easter Island is just the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

Standardized Test Prep

Multiple Choice

1. Which of the following statements about renewable resources is TRUE?
- **A** They are found only in tropical climates.
- **B** They can never be depleted.
- **C** They are replaceable by natural means.
- **D** They regenerate quickly.

2. Which of the following is a nonrenewable resource?
- **A** wind
- **B** fresh water
- **C** coal
- **D** topsoil

3. Which of the following is NOT a direct effect of deforestation?
- **A** decreased productivity of the ecosystem
- **B** soil erosion
- **C** biological magnification
- **D** habitat destruction

4. The total variation in all organisms in the biosphere is called
- **A** biodiversity.
- **B** species diversity.
- **C** ecosystem diversity.
- **D** genetic diversity.

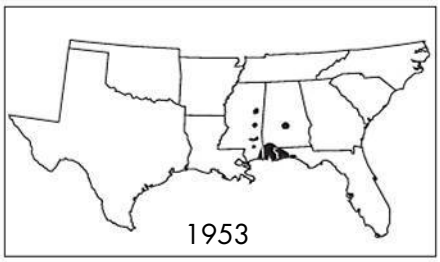
5. Ozone is made up of
- **A** hydrogen.
- **B** oxygen.
- **C** nitrogen.
- **D** chlorine.

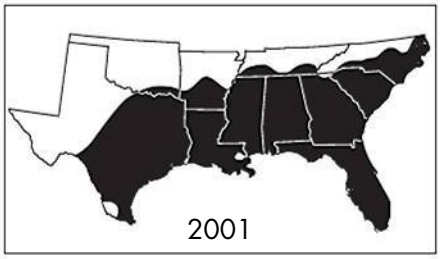
6. Ozone depletion in the atmosphere has been caused by
- **A** monoculture.
- **B** CFCs.
- **C** suburban sprawl.
- **D** soil erosion.

7. In a food chain, concentrations of harmful substances may increase in higher levels in the food chain in a process known as
- **A** biological magnification.
- **B** genetic drift.
- **C** biological succession.
- **D** pesticide resistance.

Questions 8–9

Fire ants first arrived in the United States in 1918, probably on a ship traveling from South America to Alabama. The maps below show the geographic location of the U.S. fire ant population in 1953 and 2001.





8. Which of the following statements about fire ants in the United States is TRUE?
- **A** They reproduce slowly.
- **B** They are a native species of the United States.
- **C** They are an introduced species.
- **D** They do not compete with other ant species.

9. By 2010, fire ants are MOST likely to
- **A** have spread to a larger area.
- **B** have reached their carrying capacity.
- **C** die out.
- **D** return to South America.

Open-Ended Response

10. Describe how ecologists use the ecological footprint concept.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	6.1	6.2	6.2	6.3	6.2	6.4	6.2	6.3	6.3	6.4

UNIT 2 Ecology

Unit Project

Development Debate

A large company wants to build a new factory on your town's wetlands. Many people in the town are opposed to the idea, claiming it will disturb the local ecosystem and cause problems for residents. Others support the development, arguing that the new factory will bring jobs and money into the town. Representatives have been called in to debate the issue before the town council.

Your Task Take on one of the stakeholder roles listed below. Find evidence to support that point of view and debate the issue in class. The roles are

- Conservation ecologist
- CEO of the company
- Town mayor who supports the development
- Resident of the town who lives next to the wetlands

Be sure to

- justify your arguments with credible information.
- present your arguments in a clear and convincing manner.

Reflection Questions

1. **Score your performance using the rubric below. What score did you give yourself?**
2. **What did you do well in this project?**
3. **What about your performance needs improvement?**
4. **After hearing various sides of the argument, meet with a partner and discuss which side you agree with the most. Justify your opinion.**

Assessment Rubric

Score	Evidence Provided	Quality of Performance
4	Student justifies his/her argument with sophisticated and highly credible information.	Ideas are presented in a highly convincing and clear manner. Student shows a deep understanding of the issues involved.
3	Student justifies his/her argument with logical and credible information.	Ideas are presented in an effective and clear manner. Student shows a solid understanding of the issues involved.
2	Student provides some credible information, but other points are weak or inaccurate.	Some ideas are presented in an unclear manner. Student shows a limited understanding of the issues involved.
1	Student provides mostly illogical and invalid evidence to support his/her argument.	Most ideas are presented in an unclear manner. Student shows a very limited understanding of the issues involved.

Cells

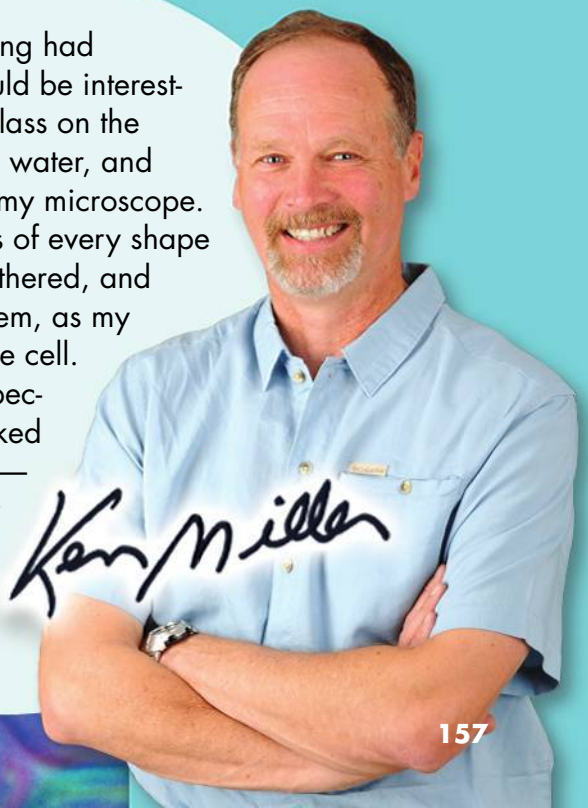
UNIT 3

Chapters

INTRODUCE the Big ideas

- **Cellular Basis of Life**
- **Homeostasis**
- **Growth, Development, and Reproduction**

"Mr. Zong had promised it would be interesting. I put a cover glass on the drop of scummy pond water, and slipped the slide under my microscope. I was amazed. Creatures of every shape and description swam, slithered, and squirmed, every one of them, as my teacher explained, a single cell. I've never forgotten the spectacle of so much life packed into such tiny packages—or the wonder of what happens inside a living cell."

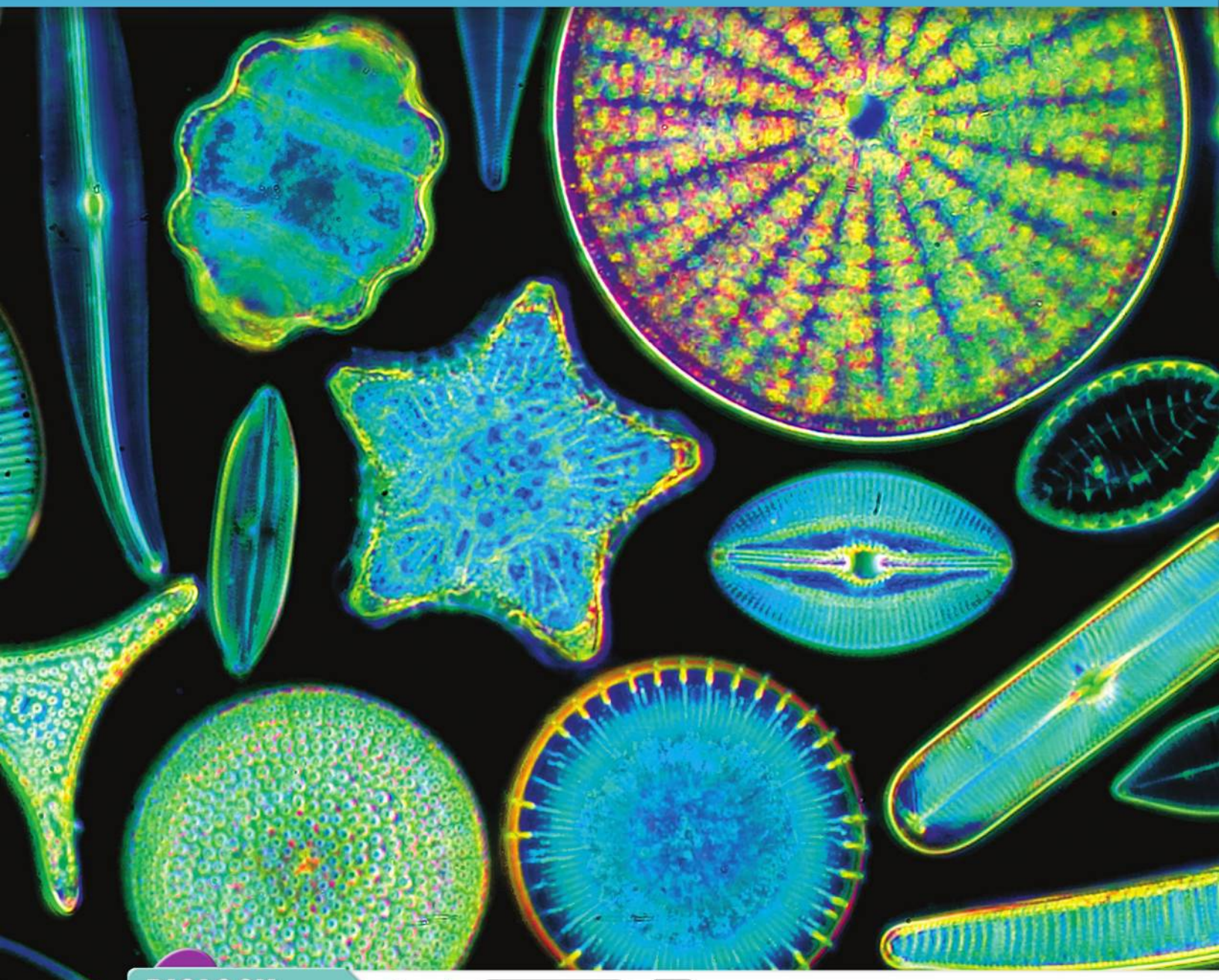


7 Cell Structure and Function

Big ideas

Cellular Basis of Life, Homeostasis

Q: How are cell structures adapted to their functions?



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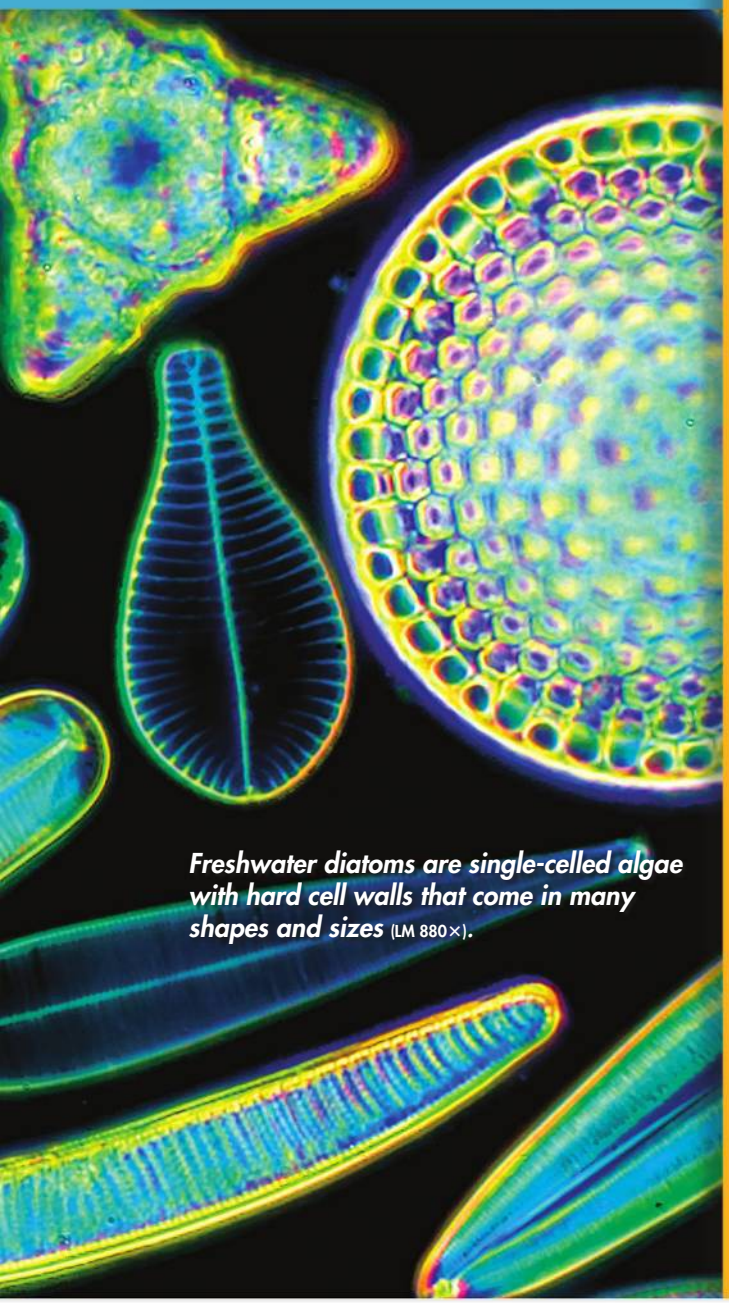
INSIDE:



Freshwater diatoms are single-celled algae with hard cell walls that come in many shapes and sizes (LM 880×).

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY

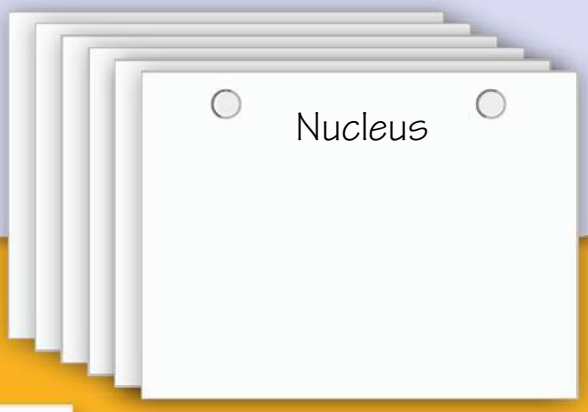
DEATH BY . . . WATER?

Michelle was healthy and 25 years old when she ran in her first marathon. The hot and humid weather made everyone sweat a lot, so Michelle drank water whenever she could. Slowly, she began to feel weak and confused. At the end of the run, Michelle staggered into a medical tent. Her head hurt and she felt nauseous. After telling a volunteer how she felt, she collapsed onto the floor. Thinking she was dehydrated, the volunteer gave Michelle even more water. But, Michelle felt worse and worse. They rushed her to the hospital, where she had a seizure and fell into a coma. Why did giving Michelle water make her condition worse?

Read for Mystery Clues As you read this chapter, look for clues to help you predict how water made Michelle sick. Then, solve the mystery at the end of the chapter.

FOUNDATIONS for Learning

Just as you have special body structures that let you do different things, cells have special parts that help keep them alive. Before you read the chapter, get 15 index cards and punch holes in them as shown below. As you read each lesson, write on the cards the name of each cell part. Draw a picture of the cell part and briefly describe what it does. At the end of the chapter are two activities that use the cards. They will help you answer the question: How are cell structures adapted to their functions?



7.1 Life Is Cellular

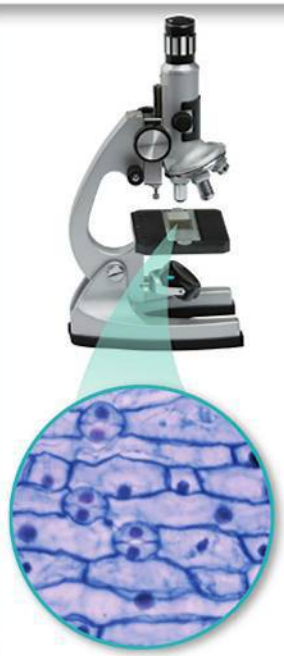
Key Questions

- ***What is the cell theory?***
- ***How do microscopes work?***
- ***How are prokaryotic and eukaryotic cells different?***

BUILD Understanding

Concept Map Make a concept map to organize information about cells. As you read, fill in the circles to show the most important parts of the concept and how they are connected.

In Your Workbook Go to your workbook to learn more about how to use a concept map. Complete the concept map activity for Lesson 7.1.



LM 35×

Cell Stains This onion leaf skin has been stained to show the shapes of the cells and some of their parts.

The Discovery of the Cell

There is an old saying that goes "Seeing is believing." A great example of this concept is the discovery of the cell. You cannot see cells with your eyes alone. Without tools to make cells visible, for centuries, scientists did not even know that there were cells. The microscope changed all of this.

Early Microscopes In the late 1500s, eyeglass makers in Europe found that they could use several glass lenses together to make very small things easy to see. Before long, they had built the first true microscopes from these lenses.

In 1665, Robert Hooke used a microscope to look at thin slices of cork from plants. The cork seemed to be made of many tiny, empty boxes. Hooke called these boxes "cells." Today we know that **cells,** which are the basic units of life, are not empty boxes. In fact, they are full of working parts, each with its own job. Cells are the smallest living unit of any organism. Around the same time that Hooke looked at cork, Anton van Leeuwenhoek looked at water. To his amazement, the microscope allowed him to see a world of tiny living things that seemed to be everywhere. He even found living bacterial cells in his own mouth.

The Cell Theory Scientists made many discoveries about cells in the next 200 years. These discoveries are summarized in the **cell theory,** a fundamental concept of biology. The cell theory states:

- All living things are made up of cells.
- Cells are the basic units of structure and function in living things.
- New cells come from existing cells.

Key Question What is the cell theory?

The cell theory states that all living things are made up of cells, that cells are the basic units of structure and function in living things, and that new cells come from existing cells.

Exploring the Cell

A microscope gives you a larger view of something very small, such as a cell. Light microscopes use glass lenses to focus light and magnify the object. Electron microscopes produce even higher magnifications by using electrons instead of light.

Light Microscopes and Cell Stains The type of microscope that you are probably most familiar with is a compound light microscope. A light microscope lets light pass through an object. Its two lenses focus the light to form an image. Some of the light scatters as it passes through the lenses. Because of this scattering of light, light microscopes can make clear images of objects only to a magnification of about 1000 times. Most living cells are nearly clear like glass. This makes it very hard to see what is inside them. So scientists use stains or dyes to show the different structures inside cells.

Electron Microscopes To study very small things, such as a DNA molecule, scientists use electron microscopes. Instead of focusing light, electron microscopes focus beams of electrons using magnetic fields. Electron microscopes can show things that are 1 billionth of a meter in size.

There are two major types of electron microscopes: transmission and scanning. Transmission electron microscopes send beams of electrons through thin slices of cells and tissues. In scanning electron microscopes, a beam of electrons is scanned over the surface of an object to give a three-dimensional image of the object's surface. Electron microscopes can be used only to look at cells and tissues that are no longer living. They make pictures that are black and white. Scientists often use computers to add "false colors" that make some structures stand out. False colors can be added to images from electron microscopes and light microscopes.

Key Question How do microscopes work?

Most microscopes use lenses to magnify the image of an object by focusing light or electrons.

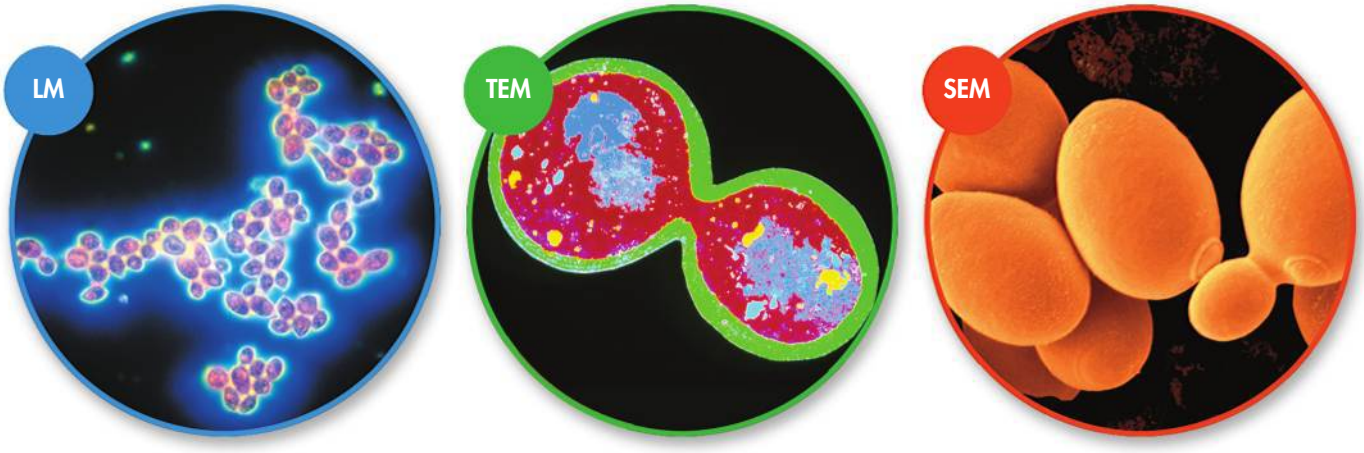
BUILD Vocabulary

cell
the basic unit of all forms of life

cell theory
a fundamental concept of biology that states that all living things are composed of cells, that cells are the basic units of structure and function in living things, and that new cells are produced from existing cells

MULTIPLE MEANINGS

The word *theory* means different things in everyday speech and in science. In everyday speech it means "a guess." In science, however, a theory is a well-tested explanation that brings together many observations and hypotheses.



Images From Microscopes Images of yeast cells from a light microscope (LM 500×), transmission electron microscope (TEM 4375×), and a scanning electron microscope (SEM 3750×)

INQUIRY into Scientific Thinking

What Is a Cell?

All living things are made up of cells. Cells are not usually visible without a microscope. In this activity, you will use a light microscope to observe several cells.

1. Obtain a slide of a plant leaf or a slice of a plant stem.
   - Look at the slide using a microscope.
   - Sketch one or more cells.
   - Describe the shape of the cells and how the different parts of a cell look.
2. Repeat step 1 with slides of nerve cells, bacteria, and paramecia.
3. Compare the cells.
   - List what they have in common.
   - List some of their differences.

Analyze and Conclude

Classify Classify the cells you studied into two or more groups. Explain what characteristics you used to put each cell in its group.

In Your Workbook Go to your workbook for more help with this activity.

BUILD Vocabulary

nucleus
a structure that contains the cell's genetic material in the form of DNA

eukaryote
an organism whose cells contain a nucleus

prokaryote
a unicellular organism that lacks a nucleus

WORD ORIGINS

The word *prokaryote* comes from the Greek word *karyon*, meaning "kernel," or nucleus. The prefix *pro-* means "before." Prokaryotic cells first came about before any cells had nuclei.

Prokaryotes and Eukaryotes

Cells come in many different shapes and sizes. Even though they are different, at some point in their lives all cells have DNA. DNA is the molecule that carries genetic information. Also, all cells are surrounded by a thin, flexible barrier called a cell membrane.

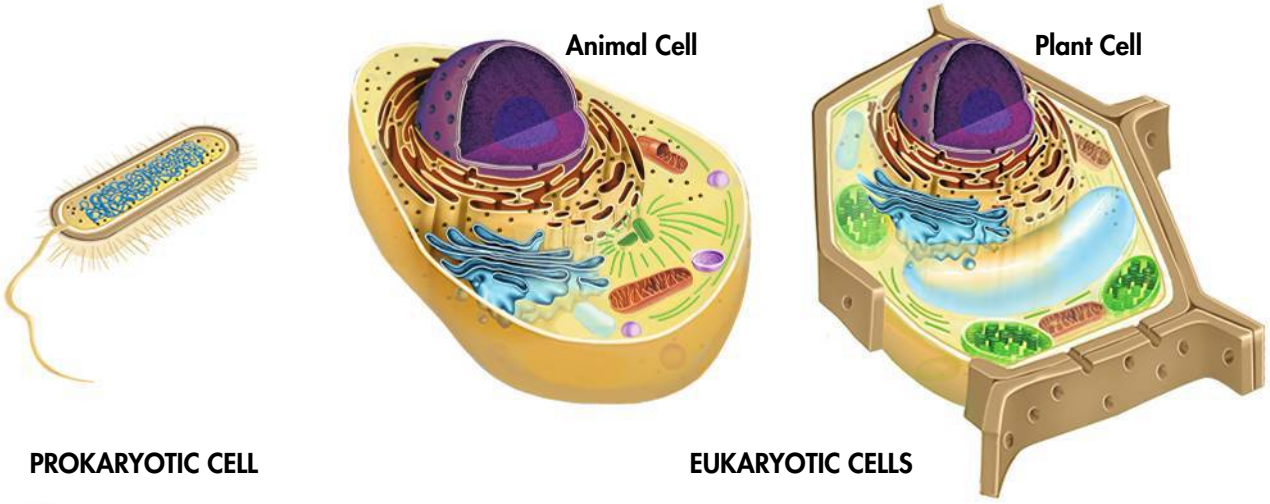
There are two main kinds of cells. One kind has a nucleus, and the other does not. The **nucleus** (plural: nuclei) holds the cell's DNA. There are two membranes around the nucleus. The nucleus also controls many of the cell's activities. **Eukaryotes** (yoo KAR ee ohts) are cells that enclose their DNA in nuclei. **Prokaryotes** (pro KAR ee ohts) are cells that do not have nuclei. Their DNA is not separated from the rest of the cell.

Prokaryotes Prokaryotic cells are generally smaller and simpler than eukaryotic cells. The DNA of prokaryotic cells is not held inside a nucleus. Instead, the DNA floats freely in the cell. Even though they are simpler than eukaryotes, prokaryotes do all the activities that living things must do to be called "alive." They grow, reproduce, respond to the environment, and, in some cases, glide along surfaces or swim through liquids. The living things that we call bacteria are prokaryotes.

Eukaryotes Eukaryotic cells are generally larger and more complex than prokaryotic cells. Most eukaryotic cells have dozens of structures and membranes inside them. Many of these structures have special jobs. In eukaryotic cells, the nucleus separates the DNA from the rest of the cell. Eukaryotes can be very different from one another. Some, like the ones commonly called "protists," live as single cells. Others make up large organisms with many cells—plants, animals, and fungi.

Key Question How are prokaryotic and eukaryotic cells different? **Prokaryotic cells do not have a nucleus. In eukaryotic cells, the nucleus separates the DNA from the rest of the cell.**

Cell Types Eukaryotic cells (including plant and animal cells) are usually more complex than prokaryotic cells.



CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. _____ are the basic units of all living things.
2. According to the _____, all living things are made of cells.
3. Cells whose DNA is held in a nucleus are _____.

Critical Thinking

4. **Apply Concepts** Bacteria cells are living in a test tube. What does the cell theory tell you about where these cells came from?
5. **Infer** A picture from a microscope is black and white and shows only the surface features of the cell. What type of microscope most likely made this picture?
6. **Compare and Contrast** How are prokaryotes and eukaryotes alike? What is the main difference between them?
7. **Write to Learn** Answer the first clue of the mystery.

MYSTERY CLUE

At the hospital, a nurse took some of Michelle's blood and looked at it under a microscope. The red blood cells looked swollen. What kind of microscope was most likely used? (Hint: See p. 161.)

BIOLOGY.com Search Lesson 7.1 GO • Lesson Assessment

7.2 Cell Structure

Key Questions

- ***What is the role of the cell nucleus?***
- ***What are the functions of vacuoles, lysosomes, and the cytoskeleton?***
- ***What organelles help make and transport proteins?***
- ***What are the functions of chloroplasts and mitochondria?***
- ***What is the function of the cell membrane?***

BUILD Understanding

Venn Diagram Create a Venn diagram that shows how prokaryotes and eukaryotes are the same and different.

In Your Workbook Go to your workbook to learn more about making a Venn diagram. Complete the Venn diagram for Lesson 7.2.

BUILD Connections

THE CELL AS A FACTORY

Each different machine and worker helps make a factory run. In much the same way, the different parts in a cell help the cell to survive.

In Your Workbook Go to your workbook for more help understanding how a cell is like a factory.

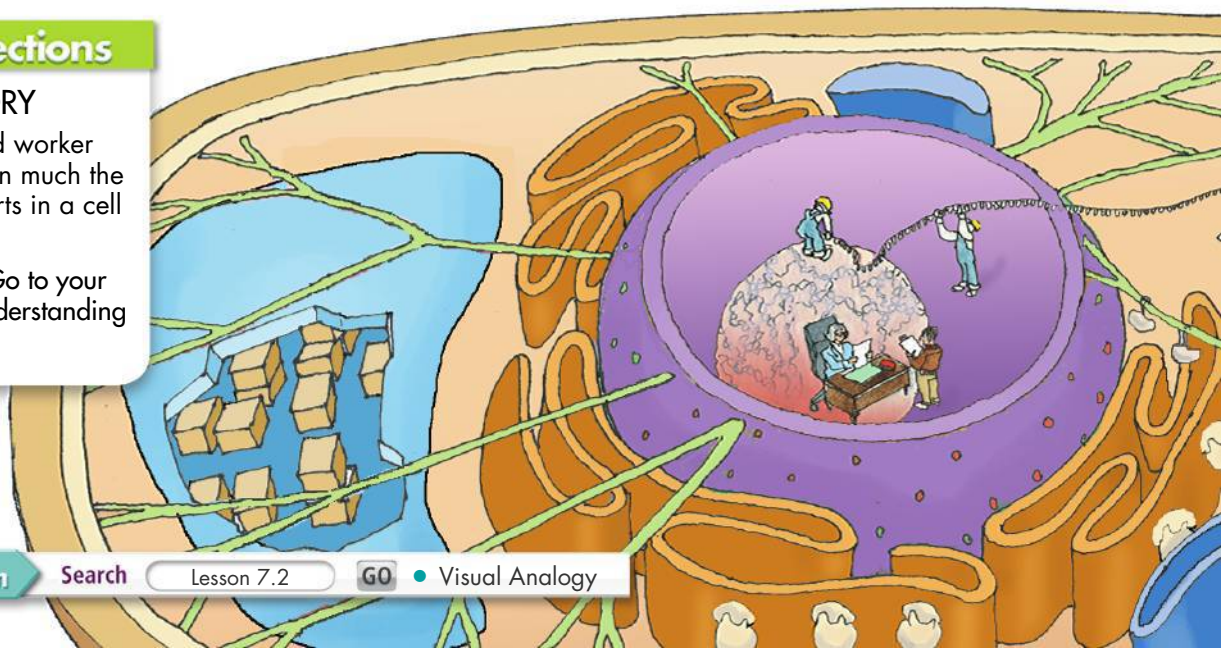
Cell Organization

Like a factory, a eukaryotic cell is a busy place with many different parts. At first glance, things may seem chaotic and disorganized. But if you look closely, you can classify those many parts into simpler categories. For example, it's easy to divide each eukaryotic cell into two major parts: the nucleus and the cytoplasm.

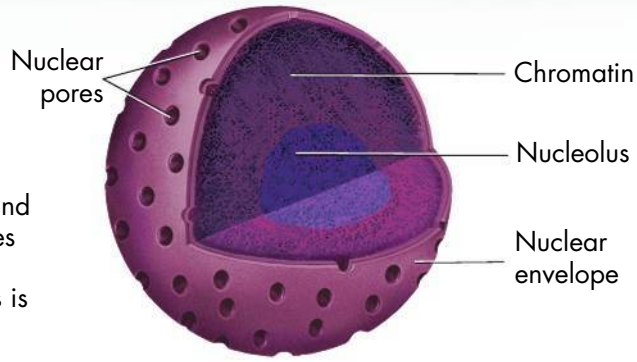
The **cytoplasm** is the portion of the cell outside the nucleus. The nucleus and cytoplasm work together to keep the cell alive. Prokaryotic cells have cytoplasm, too, even though they do not have a nucleus.

Many structures in plant and animal cells act like specialized organs. Thus, these structures are known as **organelles** or "little organs." Understanding what each organelle does for the cell can help you understand the functions of cells.

The Cell as a Factory In some ways, a eukaryotic cell is much like a factory. The different organelles of the cell are like the specialized machines, trained workers, and assembly lines of the factory. And, like workers at factories, cells follow instructions and make products. In this chapter, you will read about many ways that the parts of a cell are like the parts of a factory.



BIOLOGY.com Search Lesson 7.2 GO • Visual Analogy



The Nucleus
The nucleus holds DNA and controls most of what goes on in the cell. The small, dense area in the nucleus is the nucleolus.

The Nucleus In the same way that the main office controls a large factory, the nucleus is the control center of the cell. The nucleus holds nearly all of the cell's DNA. DNA contains the coded directions for making proteins and other important molecules. Prokaryotic cells do not have a nucleus, but they have DNA that codes the same kinds of directions.

The nucleus is surrounded by a nuclear envelope made up of two membranes. The nuclear envelope is dotted with thousands of holes. These holes allow material to move into and out of the nucleus. Messages, directions, and blueprints move in and out of a factory's main office. In a similar way, proteins, RNA, and other molecules move through the holes in the nuclear envelope to and from the rest of the cell.

Most nuclei also have a small dense spot known as the nucleolus (noo KLEE uh lus). The nucleolus is where ribosomes are first put together. Ribosomes are used by the cell to build proteins.

Key Question What is the role of the cell nucleus?
The nucleus holds nearly all of the cell's DNA, which has the coded directions for making proteins and other important molecules.

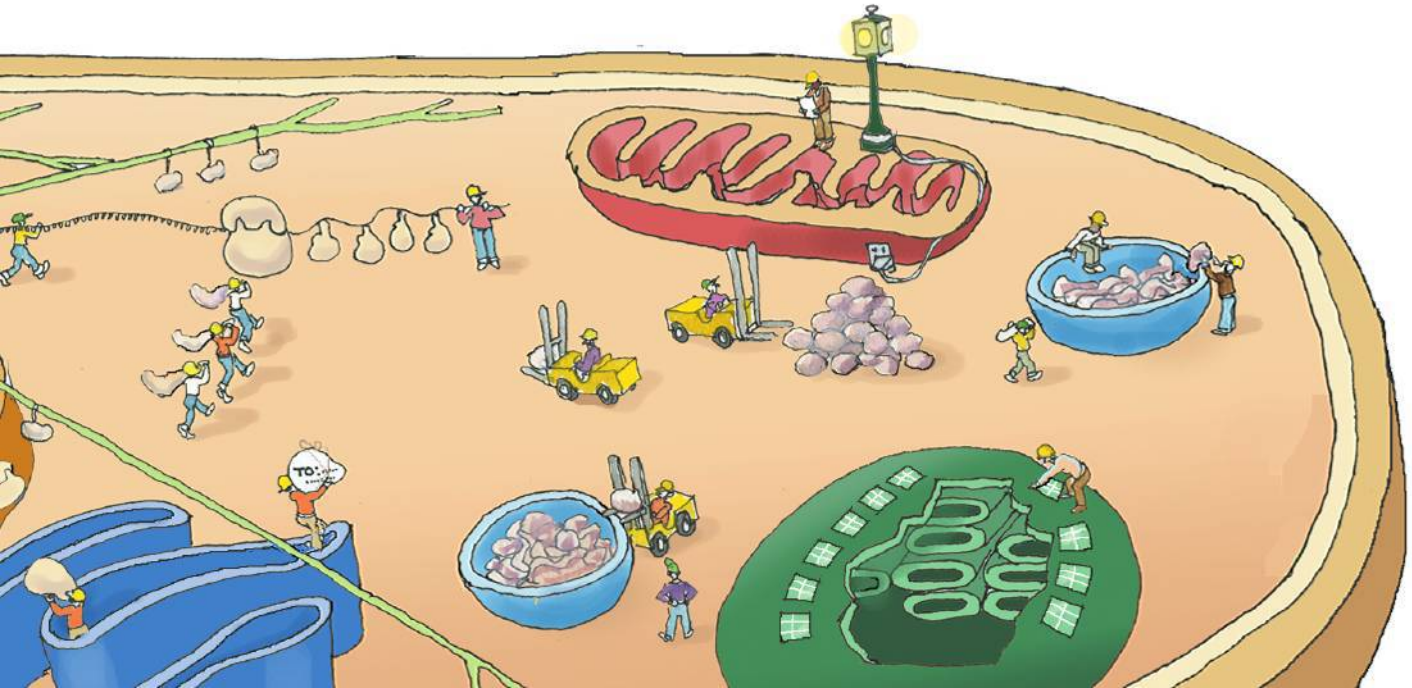
BUILD Vocabulary

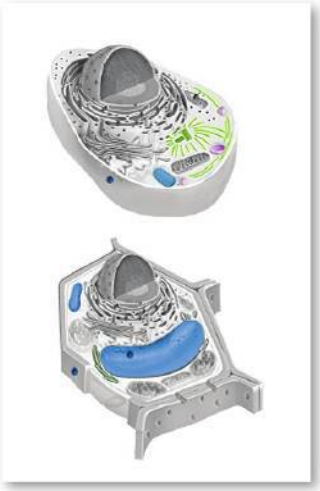
cytoplasm
the fluid portion of the cell outside the nucleus

organelle
a specialized structure that performs important cellular functions within a eukaryotic cell

WORD ORIGINS

The prefix *cyto-* comes from the Greek word *kytos*, which refers to "cell." The Greek word *plasma* means "something molded."





Organelles That Store, Clean Up, and Support

Many of the organelles outside the nucleus of a eukaryotic cell have specific functions. They include structures called vacuoles, lysosomes, and the cytoskeleton. These organelles are the cell's storage space, cleanup crew, and support structure.

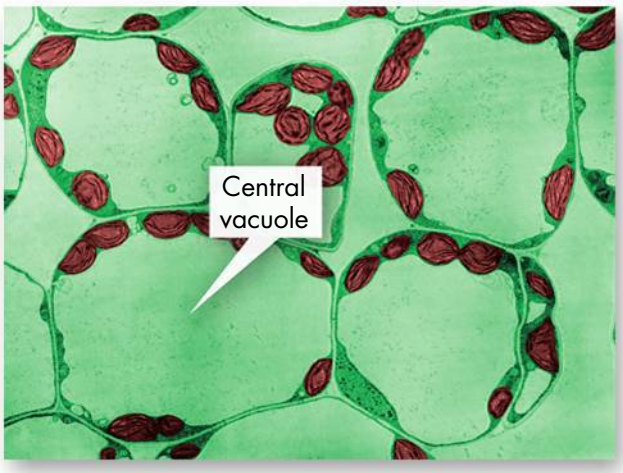
Vacuoles and Vesicles Every factory needs a place to store things. So does every cell. Many cells have large, membrane sacs called **vacuoles** (VAK yoo ohlz). Vacuoles store materials like water, salts, proteins, and sugars. In many plant cells, there is a single, large central vacuole filled with liquid. The pressure of this large vacuole makes the cell firm and lets the plant hold up heavy parts, such as leaves and flowers.

Vacuoles are also found in some single-celled organisms and in some animals. A paramecium has an organelle called a contractile vacuole. By contracting over and over, this vacuole pumps extra water out of the cell.

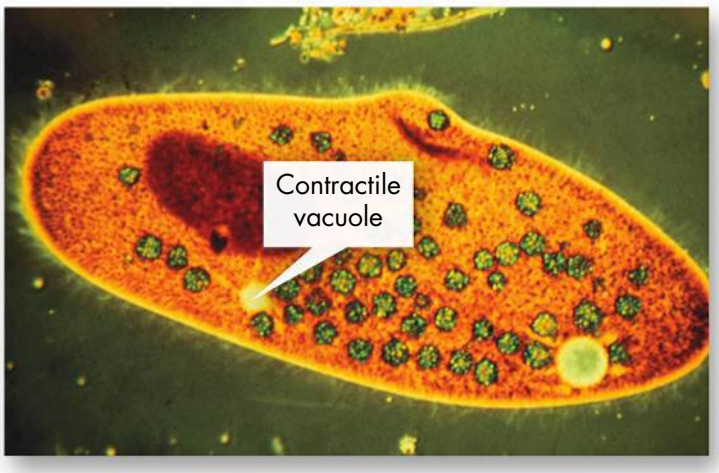
Nearly all eukaryotic cells have much smaller membrane sacs called vesicles. Vesicles store and move materials between organelles as well as to and from the outside of the cell.

Lysosomes Even the neatest, cleanest factory needs a cleanup crew. That's where lysosomes (LY suh sohmz) come in. **Lysosomes** are small organelles filled with enzymes that break down lipids, sugars, and proteins into smaller molecules. These smaller molecules can be used by the rest of the cell. Lysosomes also help break down organelles that are no longer useful. They carry out the important job of removing "junk" that might otherwise pile up in the cell. Many human diseases are linked to lysosomes that stop working correctly. Animal cells have lysosomes, and a few special kinds of plant cells also have them.

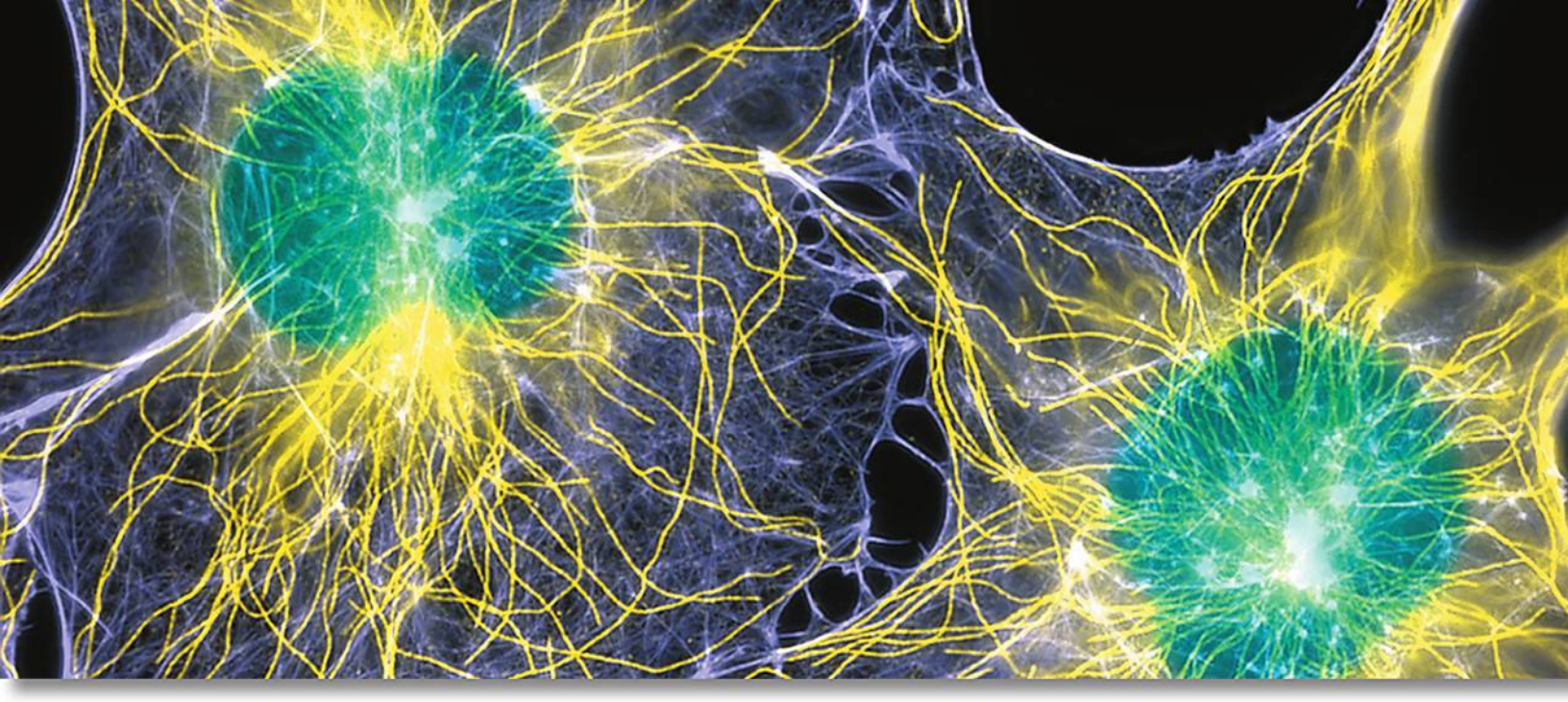
Vacuoles The central vacuole of plant cells stores salts, proteins, and sugars. A paramecium's contractile vacuole keeps the water levels just right by pumping water out.



TEM 7000×



LM 500×



LM 1175×

Cytoskeleton The cytoskeleton supports and gives shape to the cell. Dyes have been used to color different parts of the cell in this picture. Microfilaments are pale purple, microtubules are yellow, and nuclei are green.

The Cytoskeleton A factory building has strong beams and columns that hold up its walls and roof. Eukaryotic cells get their shape from a web of proteins known as the **cytoskeleton.** Some parts of the cytoskeleton help move materials between different parts of the cell. These parts are much like conveyor belts in a factory. Some cells use parts of the cytoskeleton to help them move. The cytoskeleton includes two types of protein filaments called microfilaments and microtubules.

▶ ***Microfilaments*** Microfilaments are threadlike structures made up of a protein called actin. In some cells they form an internal flexible web. This web supports the cell. Microfilaments also help some cells move. Microfilaments are built, taken apart, and then built again in different parts of the cell, allowing amoebas and other cells to crawl along surfaces.

▶ ***Microtubules*** Microtubules are like thin, hollow pipes. They are made up of proteins known as tubulins. Microtubules help the cell keep its shape. They are also found in hairlike organelles called cilia and flagella that help some cells swim. Cilia and flagella whip back and forth, pushing cells along or moving fluids along the surfaces of cells.

Microtubules are also important in cell division. They form a structure known as the mitotic spindle. This structure helps to separate the different sets of DNA that each daughter cell will get. In animal cells, organelles called centrioles (SEN tree ohlz) are also formed from tubulins. Centrioles are found near the nucleus and help organize cell division. Plant cells do not have centrioles.

Key Question What are the functions of vacuoles, lysosomes, and the cytoskeleton?

Vacuoles store materials. Lysosomes break down large molecules and old organelles. The cytoskeleton helps the cell keep its shape and move.

BUILD Vocabulary

vacuole
the cell organelle that stores materials such as water, salts, proteins, and carbohydrates

lysosome
the cell organelle that breaks down lipids, carbohydrates, and proteins into small molecules that can be used by the rest of the cell

cytoskeleton
the network of protein filaments in a eukaryotic cell that gives the cell its shape and internal organization and is involved in movement

WORD ORIGINS

The prefix *lys-* comes from the Greek word *lysis*, which refers to "loosening" or "dissolving." The suffix *-some* comes from the Greek word *soma*, which means "body." A lysosome is a small body in the cell that dissolves, or breaks up, wastes in the cell.

Organelles That Build Proteins

Living things are always working, building new molecules all the time, especially proteins. Proteins help carry out chemical reactions and make up important parts of the cell. Because proteins are so important, a big part of the cell is used for making them and moving them around.

Ribosomes Proteins are made on ribosomes. **Ribosomes** are small units of RNA and protein found in the cytoplasm of all cells. Ribosomes make proteins by following coded directions that come from DNA. Each ribosome is like a factory worker that makes proteins on orders that come from its DNA "boss." Many ribosomes are free in the cytoplasm. Others are attached to the endoplasmic reticulum.

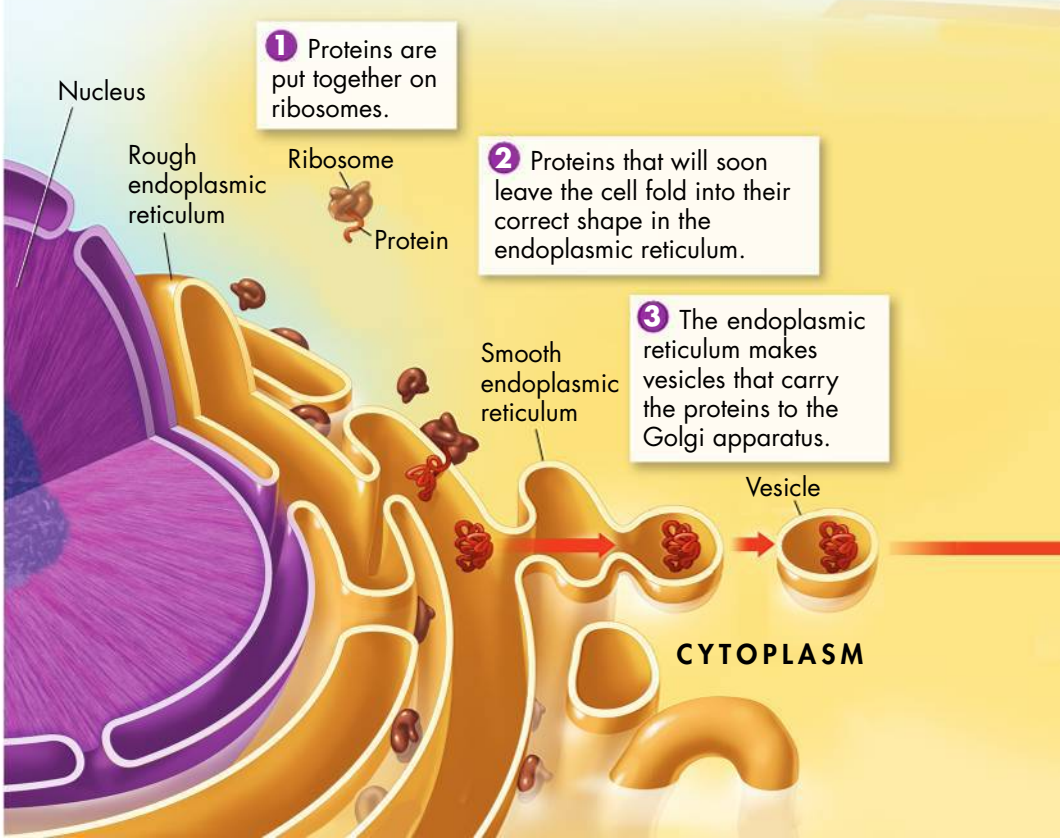
Endoplasmic Reticulum The **endoplasmic reticulum** (en doh PLAZ mik rih TIK yuh lum), or ER, is a membrane system where lipid parts of the cell membrane are put together. Proteins and other materials that are shipped from the cell are also put together on the ER. There are two types of ER: rough and smooth.

▶ ***Rough ER*** Proteins are made on the rough endoplasmic reticulum, or rough ER. It is called "rough" because the ribosomes on its surface make it bumpy. Newly made proteins leave these ribosomes and enter the rough ER. Enzymes inside the rough ER make changes to some of the proteins. Some proteins made on the rough ER will leave the cell. Others are membrane proteins and proteins that go to lysosomes and other specialized locations inside the cell.

BUILD Connections

MAKING PROTEINS

Together, ribosomes, the endoplasmic reticulum, and the Golgi apparatus make, package, and ship proteins.



▶ ***Smooth ER*** The other part of the ER is known as smooth endoplasmic reticulum, or smooth ER. It is called "smooth" because there are no ribosomes on its surface. In many cells, the smooth ER has groups of enzymes that do special tasks. They make membrane lipids and get rid of toxins, such as drugs. Liver cells, which play a key part in getting rid of drugs, often have large amounts of smooth ER.

Golgi Apparatus

In eukaryotic cells, proteins made on the rough ER move next into an organelle called the **Golgi apparatus.** This organelle looks like a stack of flat membrane sacs. It is like the "shipping station" of the cell. Proteins have molecular "address tags" that point out where they need to go. The ER "reads" these tags and bundles the proteins into tiny vesicles. The vesicles bud from the ER and carry the proteins to the Golgi apparatus. The Golgi apparatus changes, sorts, and packages proteins and other materials from the ER. Some of them are stored in the cell, while others are sent outside the cell.

Key Question What organelles help make and transport proteins?

Proteins are put together on ribosomes in the cytoplasm and on the rough ER. The Golgi apparatus changes, sorts, and packages proteins and other materials for "shipment."

BUILD Vocabulary

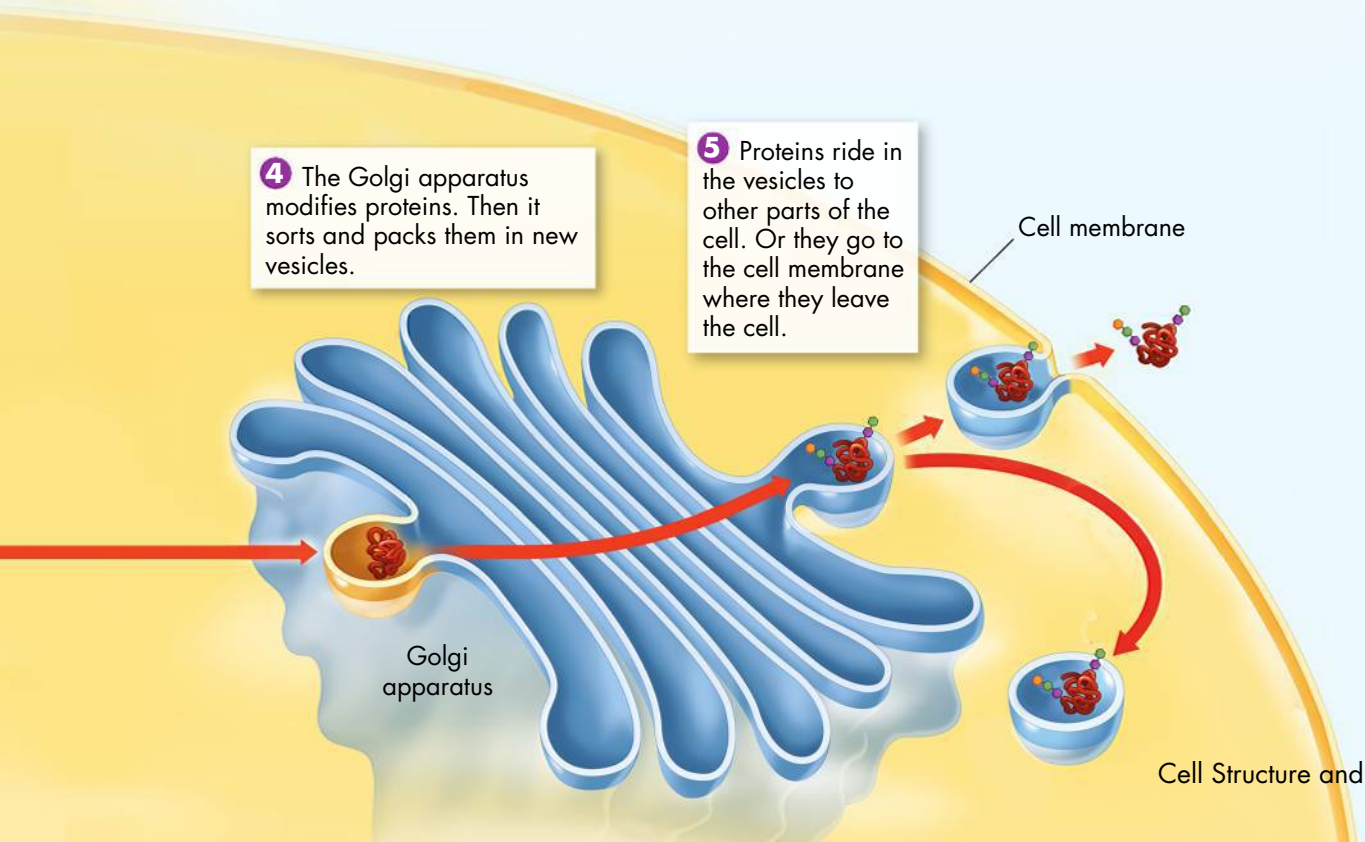
ribosome
a cell organelle consisting of RNA and protein found throughout the cytoplasm in a cell; the site of protein synthesis

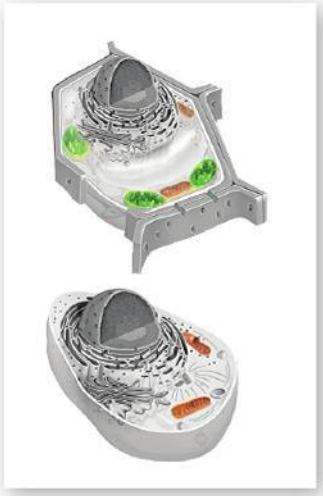
endoplasmic reticulum
the internal membrane system found in eukaryotic cells; the place where lipid components of the cell membrane are assembled

Golgi apparatus
an organelle in cells that modifies, sorts, and packages proteins and other materials from the endoplasmic reticulum for storage in the cell or release outside the cell

ACADEMIC WORDS

In everyday speech, the word *apparatus* means "equipment" or "machine." The Golgi apparatus is named for the man who first discovered it, an Italian doctor named Camillo Golgi who won a Nobel Prize in 1906.





Organelles That Capture and Release Energy

All living things need a source of energy. Factories are connected to the local power company, but how do cells get energy? Most cells are powered by food molecules that are built using energy from the sun.

Chloroplasts Plants and some other living things have chloroplasts (KLAWR uh plasts). **Chloroplasts** are like solar power plants. They take the energy from sunlight and change it into energy stored in food. This process is called photosynthesis (foh toh SIN thuh sis). Two membranes surround chloroplasts. Inside the chloroplasts are large stacks of other membranes. These hold the green pigment chlorophyll.

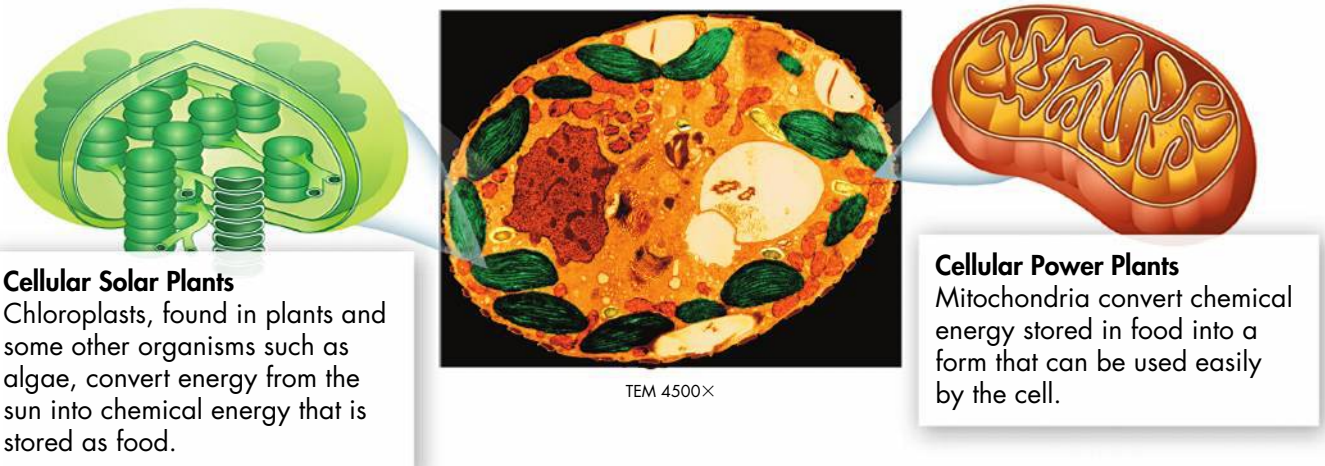
Mitochondria Nearly all eukaryotic cells, including plant cells, have mitochondria (myt oh KAHN dree uh; singular: mitochondrion). **Mitochondria** are the power plants of the cell. Mitochondria change the chemical energy stored in food into compounds that are easier for the cell to use. Like chloroplasts, mitochondria are surrounded by two membranes—an outer membrane and an inner membrane. The inner membrane is much larger than the outer one. It is folded up inside the organelle.

Chloroplasts and mitochondria have their own genetic information in the form of small DNA molecules.

Key Question What are the functions of chloroplasts and mitochondria?

Chloroplasts take the energy from sunlight and change it into food in a process called photosynthesis. Mitochondria change the chemical energy stored in food into compounds that are easier for the cell to use.

Cellular Powerhouses Chloroplasts and mitochondria both help get energy for the cell.



Cellular Solar Plants
Chloroplasts, found in plants and some other organisms such as algae, convert energy from the sun into chemical energy that is stored as food.

TEM 4500×

Cellular Power Plants
Mitochondria convert chemical energy stored in food into a form that can be used easily by the cell.

BUILD Vocabulary

chloroplast
an organelle found in cells of plants and some other organisms that captures the energy from sunlight and converts it into chemical energy

mitochondrion
a cell organelle that converts the chemical energy stored in food into compounds that are more convenient for the cell to use

lipid bilayer
a flexible double-layered sheet that makes up the cell membrane and forms a barrier between the cell and its surroundings

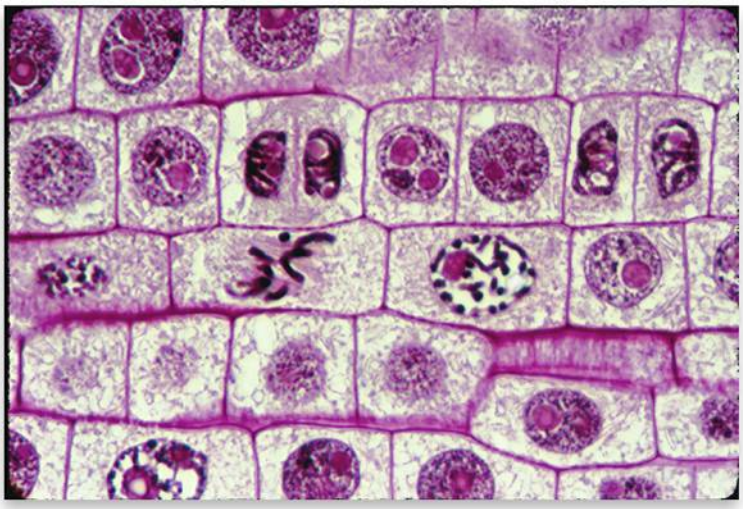
WORD ORIGINS

The Greek root *chloro-* means "green." The root *-plast* means "shape." Chloroplasts are the green-colored, round shapes in the cells of leaves.

Cellular Boundaries

A working factory needs walls and a roof to protect it from the weather outside. The roof and walls also keep the factory's products safe until they are ready to be shipped out. Cells have similar needs, and they meet them in a similar way. All cells are surrounded by a barrier known as the cell membrane. Many cells also have a stiff layer around the membrane known as a cell wall.

Cell Walls The main job of the cell wall is to support, shape, and protect the cell. Most prokaryotes and many eukaryotes, such as plant cells, have cell walls. Animal cells do not have cell walls. Cell walls lie outside the cell membrane. Most cell walls can let water, oxygen, carbon dioxide, and other materials pass through easily. Cell walls give plants the strength they need to stand up straight. In trees and other large plants, nearly all of the tissue we call wood is made up of cell walls. In fact, the cellulose fiber used to make paper, including the pages of this book, comes from these cell walls.



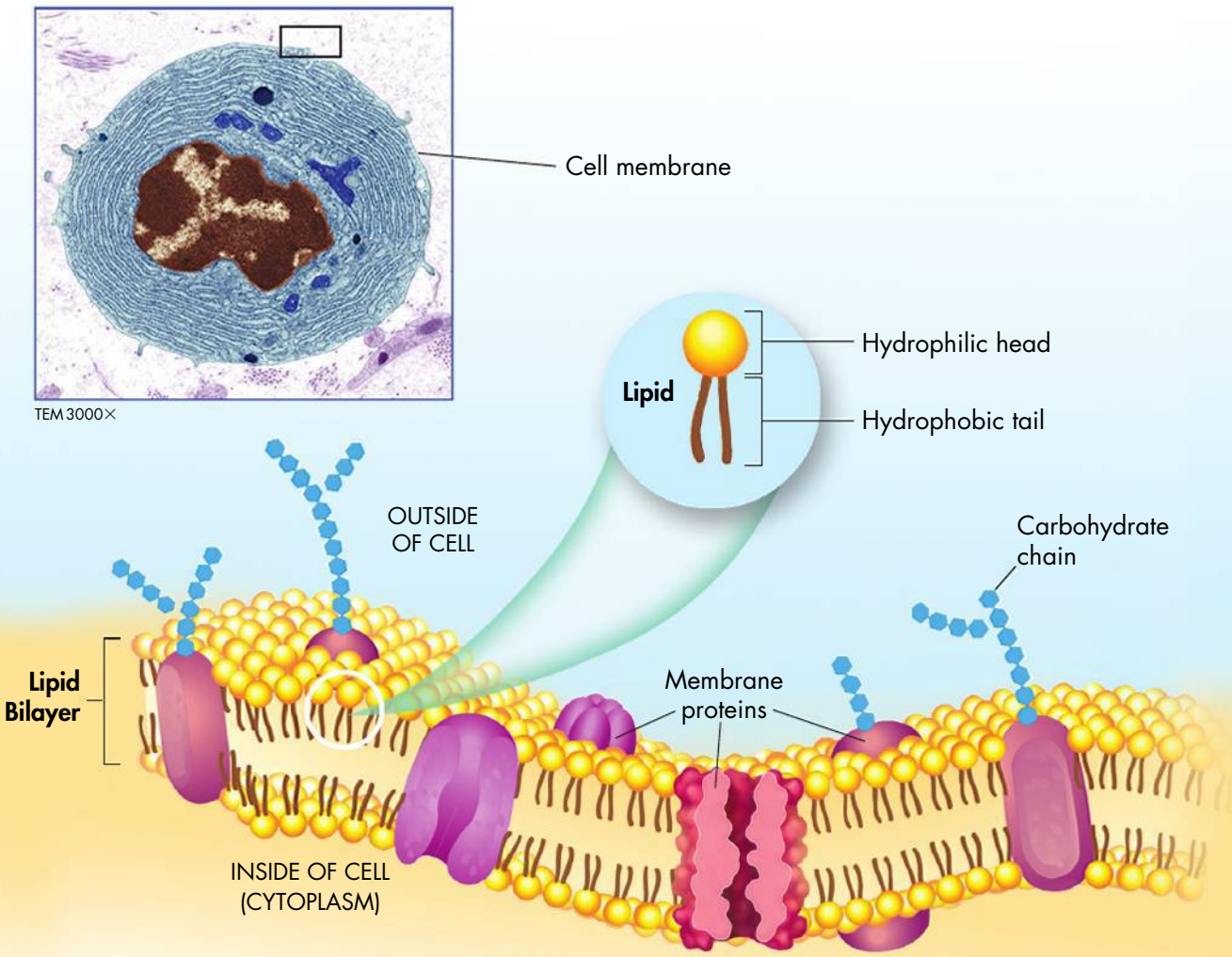
Cell Walls Rigid cell walls give these onion cells their shape (LM 700×).

Cell Membranes All cells have cell membranes. They are made up of a double-layered sheet called a **lipid bilayer.** The lipid bilayer makes membranes flexible and lets them form a strong barrier between the cell and its surroundings. The cell membrane controls what enters and leaves the cell. It also protects and supports the cell.

▶ ***Lipids*** As you can tell from the name, each layer of the lipid bilayer is made up of lipids. Lipids are large molecules made mostly from carbon and hydrogen atoms. The special lipids in the cell membrane have two parts: a head and a tail. The head is a chemical group that mixes well with water. The head is called hydrophilic, or water-loving. The tail is made up of fatty acid chains that mix well with oil. The tail is called hydrophobic, or water-hating. The difference between these heads and tails is the secret to why a cell membrane is good at its job.

When these lipids are in water, they form an ordered layer. Their oil-loving fatty acid tails stick together, while their water-loving heads mix with the water. When two of these layers come together, they are like a sandwich. The water-loving parts of the lipids form the outside layer. The oily parts of the lipids stick together to form the inner layer. A lipid bilayer is the result. As you can see in the picture below, the head groups of lipids in a bilayer are on the outside and inside of the cell. The fatty acid tails form an oily layer inside the membrane that keeps water out.

Cell Membrane The cell membrane keeps track of the movement of materials in and out of the cell. Cell membranes are made up of a lipid bilayer that has proteins and sugars set into it.



▶ ***How Membranes Work*** The lipid bilayers of most cell membranes contain many different proteins. Some of the proteins form channels and pumps that help to move material across the cell membrane. Sugar molecules are attached to many of these proteins. They act like name cards that help cells tell each other what they are doing. Other proteins attach directly to the cytoskeleton. They help the cell react to its surroundings by using the membranes to help the cell move or change shape.

As you know, some things are allowed to enter and leave a factory, and some are not. The same is true for living cells. Although many substances can cross cell membranes, some are too large to cross the lipid bilayer. Others have too much charge to pass through it. If a substance is able to cross a membrane, the membrane is said to be permeable to it. A membrane is not permeable to substances that cannot pass across it. Most cell membranes are selectively permeable, which means that some substances can pass across them and others cannot.

Key Question What is the function of the cell membrane?
The cell membrane keeps track of what enters and leaves the cell and also protects and supports the cell.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A large sac that stores water, salts, and other materials for the cell is called a _____.
2. _____ are filled with enzymes that can break down substances in cells to be used later.
3. Microtubules and microfilaments make up the _____, which helps the cell hold its shape.
4. The _____ makes up the cell membrane, which acts as a flexible protective boundary for the cell.

Critical Thinking

5. **Review** What are the two major parts of a eukaryotic cell?
6. **Use Analogies** How is the role of the nucleus in a cell similar to the role of the captain on a sports team?
7. **Apply Concepts** How do contractile vacuoles help maintain water balance in a paramecium?
8. **Sequence** Describe the steps in making, packaging, and exporting a protein from a cell.
9. **Review** What is the function of mitochondria?
10. **Write to Learn** In your own words, explain how lipid molecules are arranged in the cell membrane. In your answer, use the words *bilayer, hydrophilic,* and *hydrophobic.*

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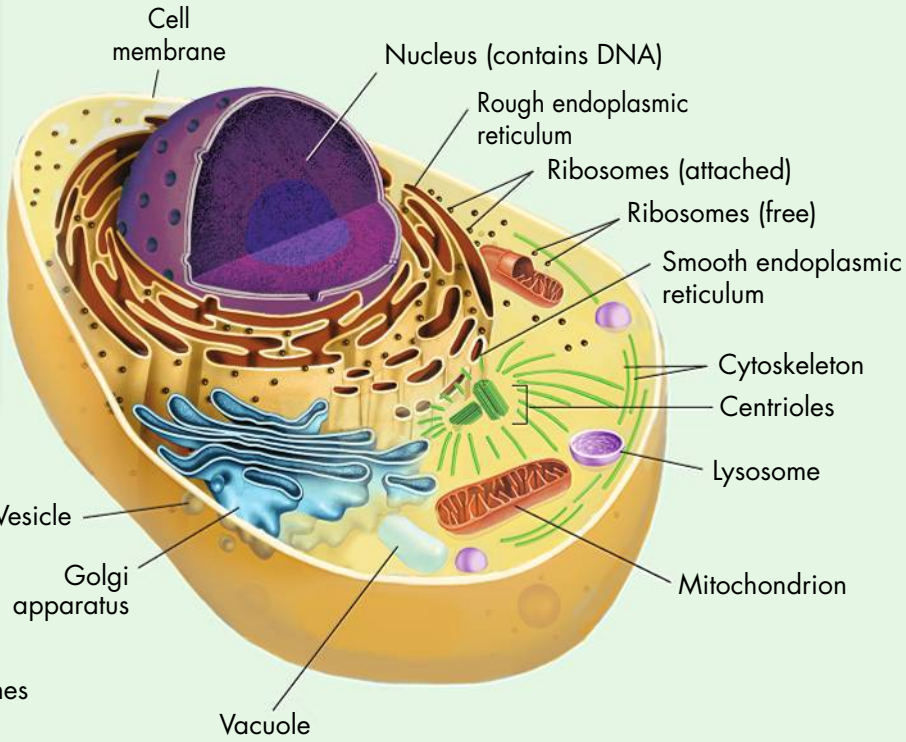
BUILD Connections

COMPARING TYPICAL CELLS

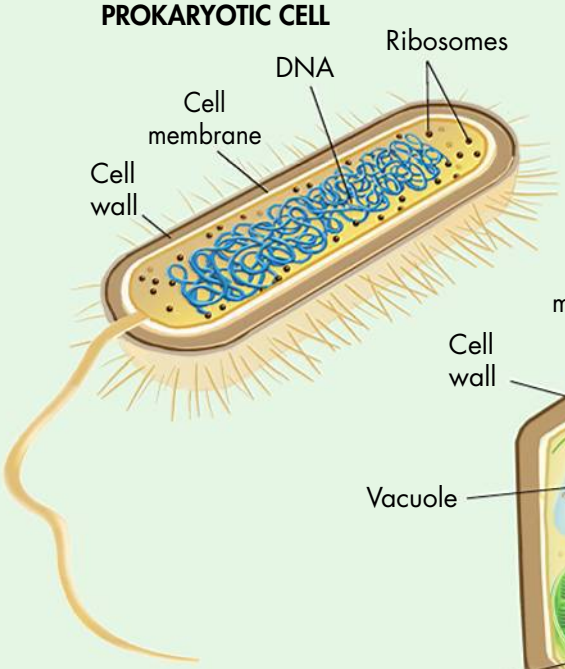
Eukaryotic cells have many different kinds of organelles. Some of these organelles are also found in prokaryotic cells. The table on the facing page compares prokaryotic cells, animal cells, and plant cells.

In Your Workbook Do you know the differences between animal cells, plant cells, and prokaryotic cells? Go to your workbook to test yourself.

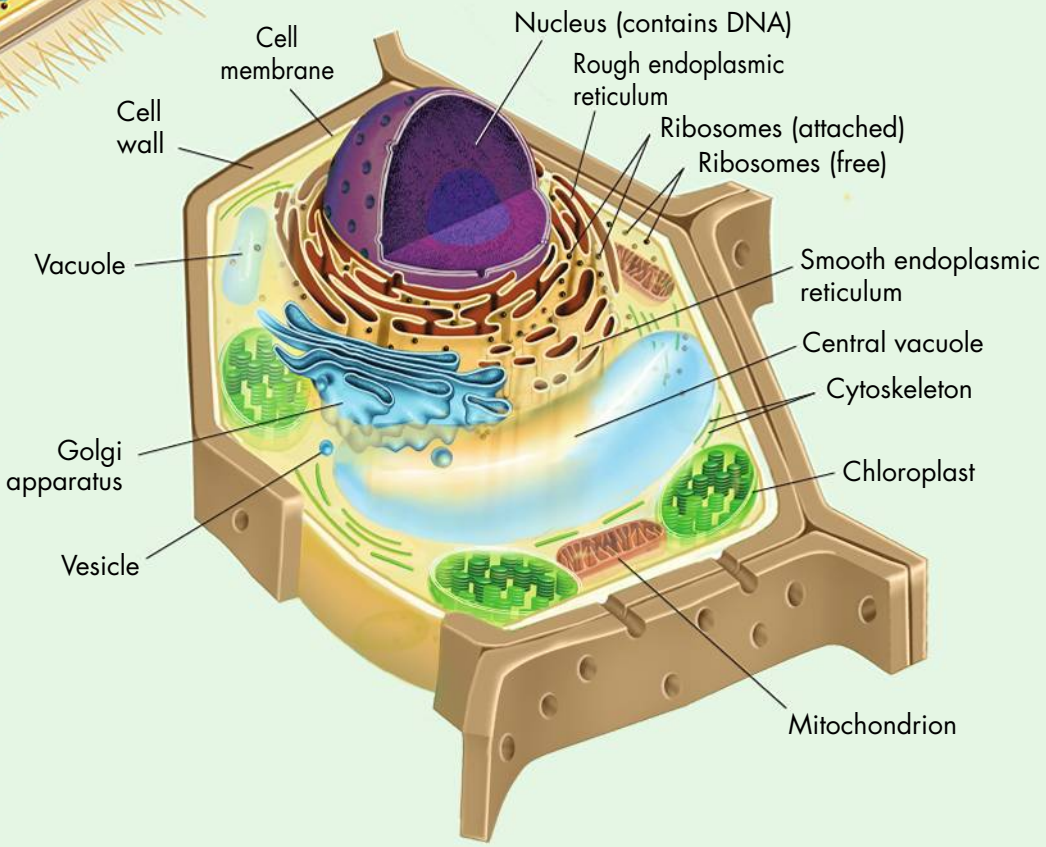
ANIMAL CELL



PROKARYOTIC CELL



PLANT CELL



	Structure	Function	Prokaryote	Eukaryote: Animal	Eukaryote: Plant
Cellular Control Center	Nucleus	Contains DNA	*Prokaryote DNA is found in cytoplasm.*	✓	✓
Organelles That Store, Clean-Up, and Support	Vacuoles and vesicles	Store materials		✓	✓
	Lysosomes	Break down and recycle macromolecules		✓	✓ (rare)
	Cytoskeleton	Maintains cell shape; moves cell parts; helps cells move	*Prokaryotic cells have protein filaments similar to actin and tubulin.*	✓	✓
	Centrioles	Organize cell division		✓	
Organelles That Build Proteins	Ribosomes	Synthesize proteins	✓	✓	✓
	Endoplasmic reticulum	Assembles proteins and lipids		✓	✓
	Golgi apparatus	Modifies, sorts, and packages proteins and lipids for storage or transport out of the cell		✓	✓
Organelles That Capture and Release Energy	Chloroplasts	Convert solar energy to chemical energy stored in food	*In some prokaryotic cells, photosynthesis occurs in association with internal photosynthetic membranes.*		✓
	Mitochondria	Convert chemical energy in food to usable compounds	*Prokaryotes carry out these reactions in the cytoplasm rather than in specialized organelles.*	✓	✓
Cellular Boundaries	Cell wall	Shapes, supports, and protects the cell	✓		✓
	Cell membrane	Regulates materials entering and leaving cell; protects and supports cell	✓	✓	✓

7.3 Cell Transport

Key Questions

- *What is passive transport?*
- *What is active transport?*

BUILD Understanding

Compare/Contrast Table As you read, create a compare/contrast table for passive and active transport.

In Your Workbook Go to your workbook for help making the compare/contrast table.

Passive Transport

Nearly every nation tries to control the things that move across its borders. A cell has a border, too. And the cell needs to control what crosses its border. The cell's border is the cell membrane.

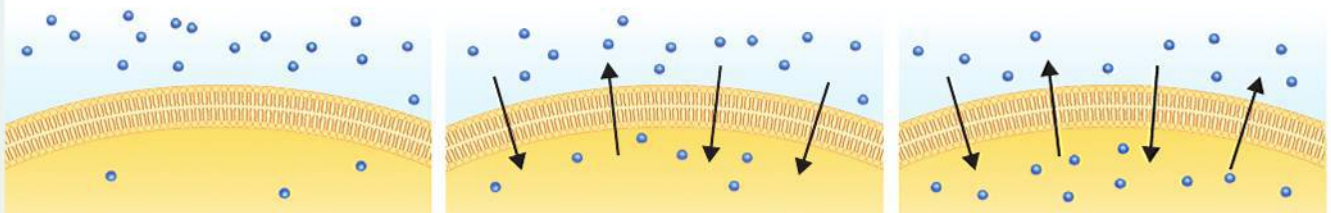
One of the most important jobs of the cell membrane is to keep up the right balance between the liquid in the cell and the liquid around the cell. It does so by keeping track of the movement of molecules across the membrane.

Diffusion Cytoplasm contains many different substances dissolved in water. These substances move in this solution, run into each other, and spread out randomly. They tend to move from an area where there are more of them to an area where there are fewer of them. Think about when you add sugar to tea. The sugar molecules will move away from their original positions and move throughout the hot liquid. The process by which particles move from an area of high concentration (close together) to an area of lower concentration (spread apart) is known as **diffusion** (dih FYOO zhun).

Suppose there is more of a substance on one side of a cell membrane than on the other. If the substance can cross the membrane, its particles will diffuse toward the area of lower concentration. The particles will keep moving to the other side until the sides are even. Once there are equal numbers on both sides, the particles will move from both sides at equal rates.

Diffusion does not need energy from the cell. The movement of materials across the cell membrane without using cellular energy is called passive transport.

Diffusion Diffusion is the process by which molecules of a substance move from an area of higher concentration (where they are closer together) to an area of lower concentration (where they are more spread out).



There are more particles on one side of the membrane than on the other. Particles are always moving across the membrane in both directions.

Diffusion causes particles to move in one direction at a faster rate. They move from the side of the membrane with the higher concentration to the side with the lower concentration.

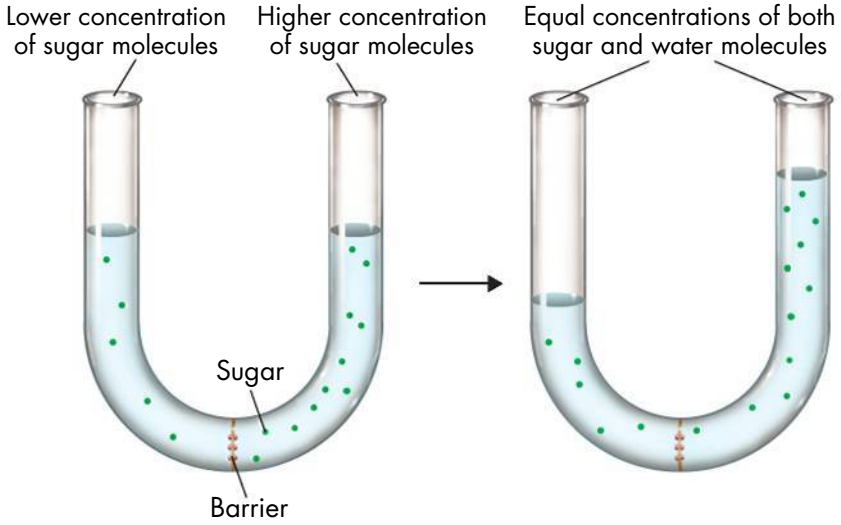
Once both sides are even, particles keep moving across the membrane in both directions at the same rate. There is no net change in concentration.

Facilitated Diffusion Remember that cell membranes are built around lipid bilayers. The lipids let small, uncharged molecules pass most easily. But many charged ions, such as Cl^-, and large molecules, such as the sugar glucose, seem to pass right through cell membranes much more quickly than they should. It's almost as if they have a shortcut.

In fact, they do. Proteins in the cell membrane act as carriers, or channels. They make it easy for certain molecules to cross. For example, red blood cells have proteins that let glucose pass through them in either direction. This process, in which molecules that cannot diffuse across the membrane alone instead pass through protein channels, is known as **facilitated diffusion.** This action does not use energy. Facilitated diffusion is a form of passive transport.

Osmosis Most cell membranes are selectively permeable. That term means they allow some things to cross, but not others. Water is a good example. The movement of water across a selectively permeable membrane is called **osmosis.** Water molecules do not mix well with lipid bilayers. So water has a hard time passing across some cell membranes. However, many cells have water channel proteins, known as aquaporins (ak wuh PAWR inz) in their membranes. These channels let water pass right through. In osmosis, as in all diffusion, molecules move from higher concentrations to lower concentrations—lower concentrations of water.

▶ ***How Osmosis Works*** Look at the picture of the U-shaped tube below. The barrier at the bottom of the tube will let water through in both directions. It will not let sugar pass. To start, there are more sugar molecules on the right side of the barrier than on the left. Even though water molecules move in both directions, they move at a greater rate toward the side with the concentrated sugar solution. Water will tend to move across the barrier until the sugar molecules on both sides are evenly spaced.



BUILD Vocabulary

diffusion
the process by which particles tend to move from an area where they are more concentrated to an area where they are less concentrated

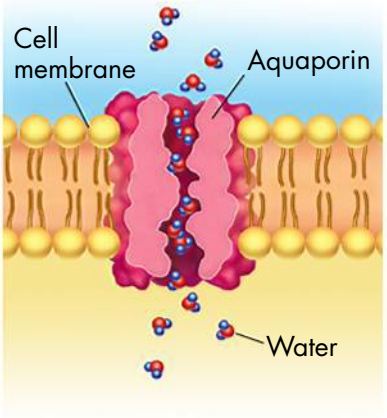
facilitated diffusion
the process of diffusion in which molecules pass across the membrane through cell membrane channels

osmosis
the diffusion of water through a selectively permeable membrane

ACADEMIC WORDS

The word *facilitate* means "to help." In facilitated diffusion, protein channels facilitate the diffusion of large molecules across the membrane.

A Water Channel Protein
Water can pass into and out of the cell through aquaporins in the cell membrane.



Osmosis In a laboratory experiment, water can move through a barrier that will not let sugar pass through it. Water molecules move from one side to the other until the sugar is evenly spaced. In the end, there will be more solution on one side of the barrier than on the other.

BUILD Vocabulary

osmotic pressure
the pressure that must be applied to prevent osmotic movement across a selectively permeable membrane

ACADEMIC WORDS

The word *pressure* means "force applied over an area." Water pressure is caused by the force of water molecules hitting the sides of their container. Osmotic pressure is caused by the difference in the forces of water molecules hitting either side of the cell membrane.

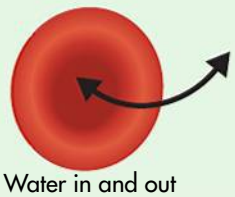
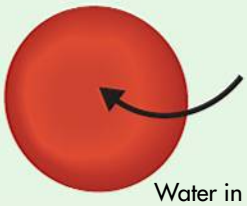
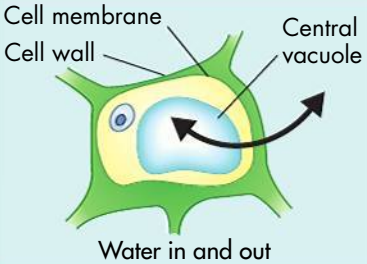
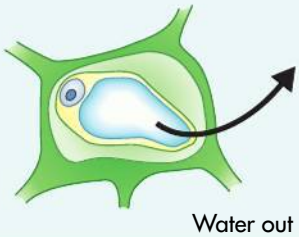
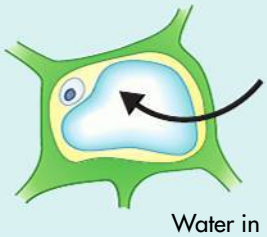
▶ ***Osmotic Pressure*** Sometimes cell membranes have solutions that are the same on both sides. Sometimes the solutions are different. When the solutions inside and outside of the cell are the same, the solutions are said to be isotonic. Isotonic means "same strength" and refers to the concentration of the dissolved particles, not the water. When the solution outside of the cell has a higher concentration than the inside solution, the outside solution is hypertonic. This word means "above strength." When the solution outside of the cell has a lower concentration, it is hypotonic, or "below strength."

Sometimes there are differences in concentration of salts, sugars, proteins, and other dissolved molecules on one side of the cell membrane. These differences produce a force known as **osmotic pressure,** which can cause the movement of water out of or into a cell through osmosis. Osmotic pressure can cause an animal cell in a hypertonic solution to shrink as water moves out. An animal cell in a hypotonic solution will swell as water moves into it. Eventually, the cell may burst like an overinflated balloon. In plant cells, osmotic pressure can cause changes in the size of the central vacuole. A shrunken central vacuole does not give the same support to the cell as a full one. This loss of support is why plants wilt when they do not get enough water.

Key Question What is passive transport?
The movement of materials across the cell membrane without using energy is called passive transport.

Osmotic Pressure Osmotic pressure inside an animal cell causes the cell to swell and burst. In plant cells, osmotic pressure inside the central vacuole pushes the cell's insides against the cell wall.

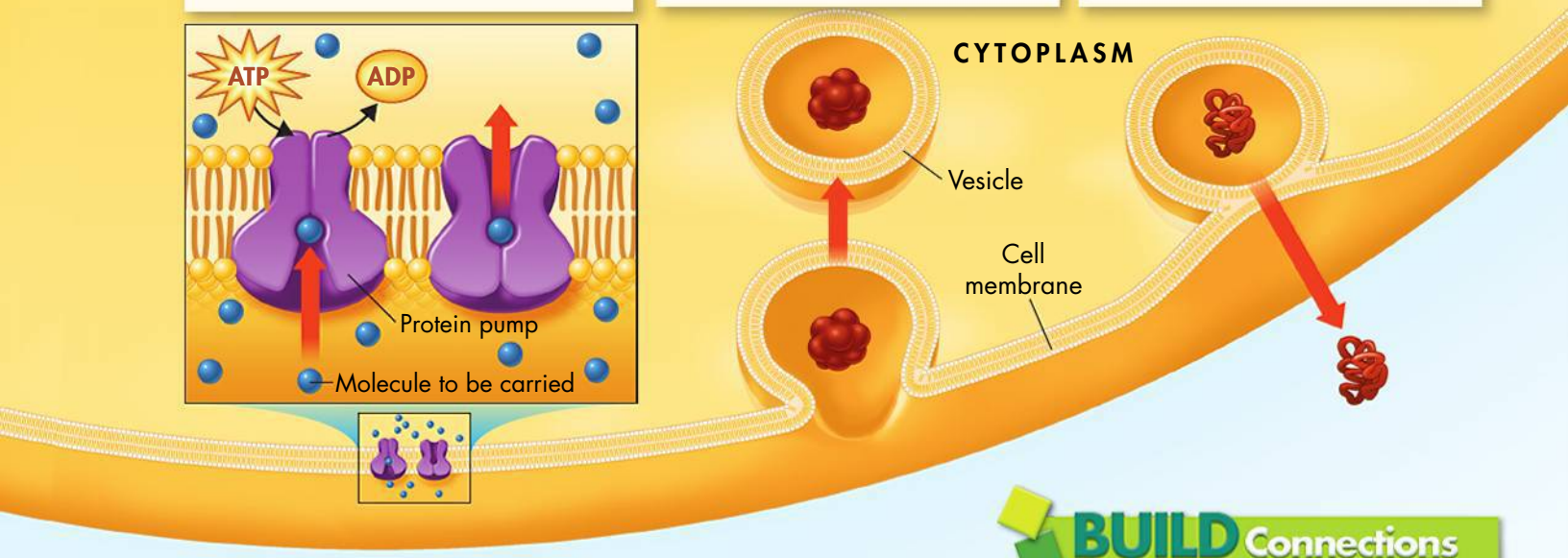
The Effects of Osmosis on Cells

Solution	**Isotonic:** The concentration is the same inside and outside the cell. Water molecules move at the same rate in both directions.	**Hypertonic:** The outside solution has a higher concentration than the solution inside the cell. Movement of water molecules out of the cell causes it to shrink.	**Hypotonic:** The outside solution has a lower concentration than the solution inside the cell. Movement of water molecules into the cell causes it to swell.
Animal Cell	 Water in and out	 Water out	 Water in
Plant Cell	 Water in and out	 Water out	 Water in

Protein Pumps
Chemical energy is used to pump ions across the cell membrane. Protein pumps grab ions on one side of the membrane, change shape, and let go of them on the other.

Endocytosis
The membrane forms a pocket around a particle outside the cell. The pocket pinches closed on the inside of the cell, forming a vesicle. The vesicle breaks loose, bringing the particle into the cell.

Exocytosis
A vesicle inside the cell carries a particle to the cell membrane. The membrane of the vesicle sticks to and becomes part of the cell membrane. The particle is forced out of the cell.



BUILD Connections

ACTIVE TRANSPORT

Energy from the cell is needed to move particles from an area of lower concentration to an area of higher concentration.

In Your Workbook Do you understand the three kinds of active transport? Go to your workbook for more practice.

Active Transport

Diffusion allows particles to move from the side of the membrane where they are crowded to the side where they are not so crowded. But what happens when the cell needs to move even more particles to the side that is already more concentrated? This takes energy. Active transport is the movement of particles across the cell membrane using energy. The major kinds of active transport are shown in the picture above. Small molecules or ions move across a cell membrane through the work of protein pumps found in the membrane. Larger molecules and big clumps of material can also be moved across the cell membrane by processes known as endocytosis and exocytosis.

Moving Molecules Small molecules and ions are carried across membranes by proteins that act like pumps. Many cells use protein pumps to move calcium, potassium, and sodium ions across cell membranes. Changes in protein shape seem to be an important part of the pumping process. Chemical energy causes a change in the shape of the protein, so the protein binds the substance on one side of the membrane, then lets it go on the other side. A lot of the energy used by cells in their daily activities goes toward keeping active transport working. Using energy lets cells move substances to concentrated areas, even when diffusion might tend to move these substances in the opposite direction.

BIOLOGY.com Search Lesson 7.3 GO • Art in Motion

Endocytosis This white blood cell is taking in a damaged red blood cell through endocytosis. "Arms" of the white blood cell's cell membrane have completely surrounded the red blood cell (TEM 5300×).

Moving Larger Particles Larger molecules and even solid clumps of material cannot pass through protein pumps. They must be moved from one side of the membrane to the other through vesicles. Two types of active transport that use vesicles to move larger particles are endocytosis and exocytosis.

▶ ***Endocytosis*** Endocytosis (en doh sy TOH sis) is the process of taking material into the cell through a pocket of the cell membrane that folds into the cell. The pocket pinches off and breaks loose from the cell membrane. It then forms a vesicle or vacuole in the cytoplasm. Large molecules, clumps of food, and even whole cells can be taken up in this way. Amoebas use this method for taking in food. White blood cells also use endocytosis to "eat" damaged cells. Taking in material in this way uses a lot of energy. It is a form of active transport.

▶ ***Exocytosis*** Many cells release large amounts of material through a process known as exocytosis (ek soh sy TOH sis). Exocytosis is the opposite of endocytosis—materials leave the cell instead of coming into it. During exocytosis, the membrane of a vesicle sticks to and becomes part of the cell membrane. As the membranes fuse, the contents of the vesicle are forced out of the cell. Cells use exocytosis to get rid of wastes and to give off chemical signals.

Key Question What is active transport?
The movement of materials from an area of lower concentration to an area of higher concentration is known as active transport. Active transport requires energy.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Diffusion of particles through protein channels is called _____.

2. Osmosis produces a force known as _____.

Critical Thinking

3. Compare and Contrast How is endocytosis similar to exocytosis? How are they different?

4. Apply Concepts What would happen to the cells of a saltwater plant if the plant were placed in fresh water?

5. Write to Learn Answer the second clue of the mystery.

MYSTERY CLUE

As Michelle ran, she sweated. Sweating made her lose salts from her bloodstream. As she drank more water, the concentration of salts and minerals in her bloodstream got lower. How do you think these things made Michelle's problem worse? (Hint: See p. 176.)

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7.4 Homeostasis and Cells

The Cell as an Organism

It is sometimes hard to remember that all living things have certain characteristics in common. All living things are made of cells. They all have the same kinds of organelles. But, clearly, living things are not all the same.

Sometimes, a single cell is the whole organism. In fact, there are many more single-celled organisms on Earth than there are organisms with many cells. Just like other living things, single-celled organisms must maintain **homeostasis**—relatively constant internal physical and chemical conditions. To stay in this state single-celled organisms grow, respond to the environment, change food or sunlight into useful energy, and reproduce.

Single-celled organisms include both prokaryotes and eukaryotes. Prokaryotes, especially bacteria, are very adaptable. They live almost everywhere—in the soil, on leaves, in the ocean, in the air, and even within the human body. Many eukaryotes also spend their lives as single cells. Some types of algae are single cells found in oceans, lakes, and streams around the world. Yeasts, or unicellular fungi, have an important job breaking down nutrients, making them available for other living things.

Key Question How do individual cells maintain homeostasis?
To maintain homeostasis, unicellular organisms grow, respond to the environment, change food or sunlight into useful energy, and reproduce.

Single-Celled Life Single-celled organisms, like this freshwater protozoan, must be able to carry out all of the functions necessary for life (SEM 600×).

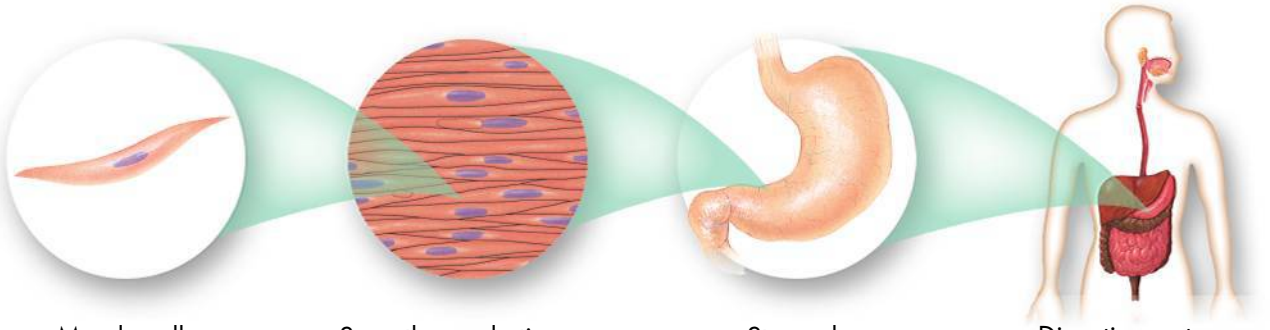
Key Questions

- ***How do individual cells maintain homeostasis?***
- ***How do the cells of multicellular organisms work together to maintain homeostasis?***

BUILD Understanding

Preview Visuals Before you read, look at the Levels of Organization image at the top of the next page. Then write two questions you have about the figure. As you read, write answers to your questions.

In Your Workbook Go to your workbook for help answering your questions. Complete the preview visuals activity for Lesson 7.4.



Levels of Organization From simplest to most complex, the levels of organization in a many-celled organism are cells, tissues, organs, and organ systems.

Multicellular Life

The cells of human beings and other many-celled organisms do not live on their own. They need other cells to survive. Like the members of a winning baseball team, they must work together. In baseball, each player plays a different position. To play the game well, players communicate with one another, sending and receiving signals. Cells in a many-celled organism work the same way. They become specialized for certain jobs. They communicate with one another to maintain homeostasis.

Cell Specialization The cells of a many-celled organism are specialized. Different kinds of cells have different jobs. Some cells are specialized for movement. Others must react to the environment. Still others must make substances that the organism needs. No matter what its job, each specialized cell helps the organism maintain homeostasis. For example, cells that line the air passages in your lungs have cilia (SIL ee uh). These hairlike parts sweep dust away to keep your lungs clean. These specialized cells are packed with mitochondria that make the chemical energy that powers their cilia.

Levels of Organization The specialized cells of many-celled organisms are organized into tissues. A **tissue** is a group of similar cells that that work together to do a particular job. Many tasks in the body are too complicated to be carried out by just one kind of tissue. In these cases, groups of tissues work together as an **organ.** For example, each muscle in your body is an organ. Within a muscle, however, there are nervous tissues and connective tissues. Each kind of tissue has a special job that helps the organ do its job. A group of organs that work together to do a job is called an **organ system.** For example, the stomach, pancreas, and intestines work together as the digestive system to break down food and take up nutrients.

BUILD Vocabulary

homeostasis
the relatively constant internal physical and chemical conditions that organisms maintain

tissue
a group of similar cells that perform a particular function

organ
a group of tissues that work together to perform closely related functions

organ system
a group of organs that work together to perform a specific function

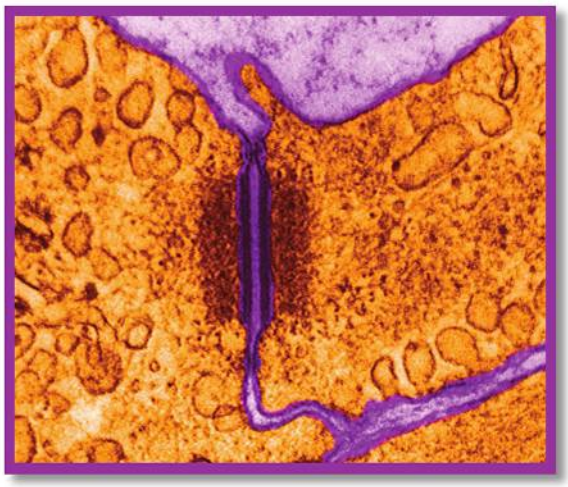
PREFIXES

The prefix *homeo-* means "the same." Living things are always trying to maintain homeostasis. They must keep their internal physical and chemical conditions about the same at all times, in spite of changes in their environments.

Cellular Communication Cells in a large organism use chemical signals to communicate. These chemical signals are passed from one cell to another. They can speed up or slow down the activities of the cells that receive them. They can even cause a cell to change what it is doing in an instant.

In order to communicate, certain cells form connections, or cellular junctions, to neighboring cells. Some of these junctions hold cells together firmly. Others allow small molecules carrying chemical messages or signals to pass from one cell to the next. To "understand" one of these chemical signals, a cell must have a receptor that sticks to the chemical signal. Some receptors are on the cell membrane. Other kinds of receptors are inside the cytoplasm.

The chemical signals sent by different kinds of cells can cause important changes in cells and tissues. For example, the signal that causes heart muscle cells to contract begins in a place known as the pacemaker. Ions carry the signal from cell to cell through a special connection known as a gap junction. This junction can cause the millions of heart muscle cells to contract as one in a single heartbeat.



Cellular Junctions Some junctions, like the one seen in brown in this micrograph of capillary cells in the gas bladder of a toadfish, hold cells together in tight formations (TEM 21,600×).

Key Question How do the cells of multicellular organisms work together to maintain homeostasis?

The cells of many-celled organisms have specialized jobs and communicate with one another to maintain homeostasis.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. _____ is the relatively constant internal physical and chemical conditions of a cell or organism.
2. Many similar specialized cells working together make up a(n) _____.
3. Many organs make up a(n) _____.

Critical Thinking

4. **Review** What is homeostasis?
5. **Explain** What do unicellular organisms do to maintain homeostasis?
6. **Predict** Using what you know about the ways muscles move, predict which organelles would be most common in muscle cells.
7. **Apply Concepts** The contractile vacuole is an organelle found in some single-celled organisms. Contractile vacuoles pump out fresh water that builds up in the cell from osmosis. How is this activity an example of the way the cell maintains homeostasis?
8. **Sequence** List the different levels of organization in many-celled organisms from most complex to least complex.
9. **Write to Learn** Write a paragraph that explains how cells in a many-celled organism are like teammates on a sports team.

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Pre-Lab: Detecting Diffusion

Problem How can you determine whether solutes are diffusing across a membrane?

Materials 400-mL beaker, 25-mL graduated cylinder, 1% starch solution, plastic sandwich bag, twist tie, iodine solution, forceps

Lab Manual Chapter 7 Lab

Skills Focus Use Models, Infer, Compare and Contrast

Connect to the Big idea The cell membrane forms a thin flexible barrier between a cell and its surroundings. The cell membrane controls what enters the cell and what leaves the cell. Diffusion is the process responsible for much of the movement across a cell membrane. During diffusion, solutes move from an area of high concentration to an area of lower concentration. When water is the molecule that is diffusing, the process is called osmosis. Proteins embedded in the membrane can facilitate the diffusion of many particles, including water. In this lab, you will model the diffusion of small molecules.

Background Questions

a. **Review** What does it mean to say that a membrane is selectively permeable?

b. **Explain** Does the movement of molecules stop when the concentration of a solute is equal on both sides of a membrane? Explain.

c. **Compare and Contrast** What is the main difference between passive transport and active transport?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Draw Conclusions** How will you know whether starch has diffused across the membrane?

2. **Draw Conclusions** How will you know whether iodine has diffused across the membrane?

3. **Use Analogies** How is a window screen similar to a cell membrane?

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Visit Chapter 7 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Travel to the ocean's depths with the Untamed Science crew to explore how fish maintain water homeostasis.

Art in Motion View a short animation that explains the different types of active transport.

Art Review Review your understanding of plant and animal cell structures with this activity.

InterActive Art Build your understanding of osmosis and diffusion with these animations.

Visual Analogy Compare the structures of the cell to the parts of a factory.

Tutor Tube Hear suggestions from the tutor for help in remembering cell structures.

7 CHAPTER Summary

7.1 Life Is Cellular

- The cell theory states that (1) all living things are made up of cells, (2) cells are the basic units of structure and function in living things, and (3) new cells come from existing cells.
- Most microscopes use lenses to magnify the image of an object by focusing light or electrons.
- Prokaryotic cells do not have a nucleus. In eukaryotic cells, the nucleus holds the cell's genetic material.

cell (p. 160)
cell theory (p. 160)
nucleus (p. 162)
eukaryote (p. 162)
prokaryote (p. 162)

7.2 Cell Structure

- The nucleus holds nearly all of the cell's DNA.
- Vacuoles store water, salts, proteins, and sugars. Lysosomes break down old organelles and large molecules so that they can be used by the cell. The cytoskeleton helps the cell move and keep its shape.
- Proteins are put together on ribosomes.
- Proteins that will leave the cell and many kinds of membrane proteins are made on the rough ER. The Golgi apparatus then changes, sorts, and packages proteins for storage in the cell or for leaving the cell.
- Chloroplasts take the energy from sunlight and change it into chemical energy stored in food in a process called photosynthesis. Mitochondria change the chemical energy of food into compounds that are easier for the cell to use.
- The cell membrane keeps track of what enters and leaves the cell. It also protects and supports the cell.

cytoplasm (p. 164)
organelle (p. 164)
vacuole (p. 166)
lysosome (p. 166)
cytoskeleton (p. 167)
ribosome (p. 168)
endoplasmic reticulum (p. 168)
Golgi apparatus (p. 169)
chloroplast (p. 170)
mitochondrion (p. 170)
lipid bilayer (p. 171)

7.3 Cell Transport

- Passive transport is the movement of materials across the cell membrane without using energy. Diffusion, facilitated diffusion, and osmosis are kinds of passive transport.
- Active transport uses energy. It is the movement of materials from an area of lower concentration to an area of higher concentration. Protein pumps, endocytosis, and exocytosis are kinds of active transport.

diffusion (p. 176)
facilitated diffusion (p. 177)
osmosis (p. 177)
osmotic pressure (p. 178)

7.4 Homeostasis and Cells

- To maintain homeostasis, single-celled organisms grow, respond to the environment, get and use energy, and reproduce.
- The cells of living things that have many cells become specialized for particular jobs. These cells must communicate with one another to maintain homeostasis.

homeostasis (p. 181)
tissue (p. 182)
organ (p. 182)
organ system (p. 182)

7 CHECK Understanding

Assess the Big idea — Cellular Basis of Life, Homeostasis

Write an answer to the question below.
Q: How are cell structures adapted to their functions?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs long. To help you begin, read the **Hints** below each of the questions.

1. **Infer** Prokaryotic cells have some structures in common with plant cells and some structures in common with animal cells. Which two types of cells are MOST likely more closely related to one another? Explain your reasoning.

   Hint Prokaryotic cells have cell walls, and some can carry out photosynthesis like plant cells can. However, they do not have a nucleus.

   Hint Plant and animal cells have organelles that are enclosed by membranes, which prokaryotic cells do not have.

2. **Analyze Concepts** What happens to lipids when they are dropped into water? How does this action explain the structure of cell membranes?

   Hint Lipids have a head that mixes well with water and a tail that mixes well with oil.

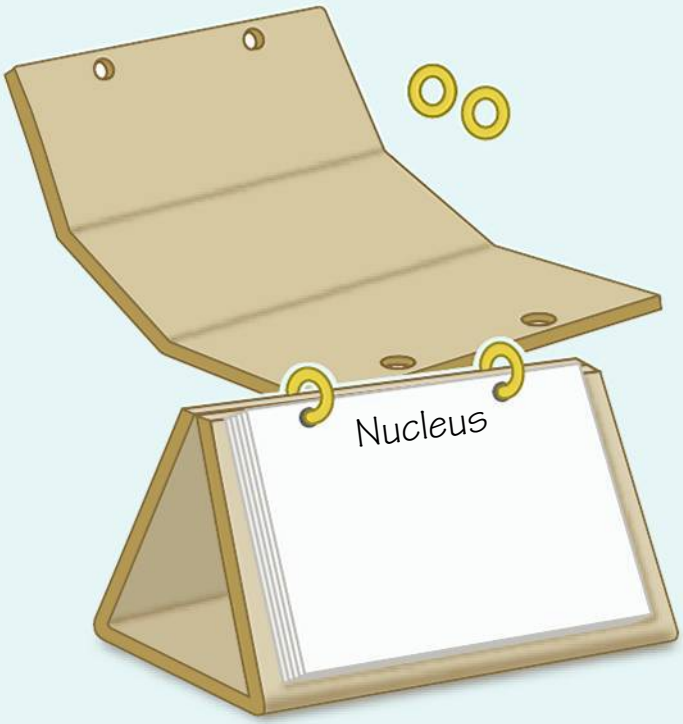
   Hint Cell membranes are made up of lipid bilayers.

Foundations for Learning Wrap-Up

Use the index cards you prepared when you started the chapter as a tool to help you organize what you learned about the structure and function of cell parts.

Activity 1 Recall that different kinds of cells can have different cell parts. Sort the cards into four piles. The first pile should be cell parts that all cells have. The second pile should be cell parts that only animal cells have. The third pile should be cell parts that only plant cells and animal cells have. The fourth pile should be cell parts that only plant cells and bacteria cells (prokaryotes) have. Label the bottom right-hand corner of each card with the letters *A*, *P*, and *B* (animal, plant, and bacteria) accordingly to show which type of cell has each cell part.

Activity 2 Using metal or plastic rings and a piece of cardboard, combine your cards into a flip chart as shown below. Work with a partner to write a lesson on cell parts that uses the flip chart to explain important concepts from the chapter. Then use the flip chart to present your lesson to a classmate.



7.1 Life Is Cellular

Understand Key Concepts

1. In many cells, the structure that controls the cell's activities is the
   a. cell membrane. **c.** nucleolus.
   b. organelle. **d.** nucleus.

2. Cells can be very different in size, shape, and the types of organelles they have. However, at some point all cells have DNA and
   a. a cell wall. **c.** mitochondria
   b. a cell membrane. **d.** a nucleus.

Test-Taking Tip

Watch for Qualifiers When you are answering a question, watch out for words such as *all*, *none*, *always*, and *not*. In question 2, notice the word *all*. This question is asking what part ALL cells have in common. You know animal cells do not have a cell wall and prokaryotes do not have a nucleus or organelles. Mitochondria are organelles. All cells must have a cell membrane. The correct answer is b.

3. What three statements make up the cell theory?

Think Critically

4. **Infer** How did the invention of the microscope help scientists come up with the cell theory?

7.2 Cell Structure

Understand Key Concepts

5. In eukaryotic cells, the cell's genetic information is found in the
   a. ribosomes. **c.** nucleus.
   b. lysosomes. **d.** cell membrane.

6. The organelles that break down lipids, sugars, and proteins into small molecules that can be used by the cell are called
   a. vacuoles. **c.** ribosomes.
   b. lysosomes. **d.** microfilaments.

7. Cell membranes are made up of
   a. lipid bilayers. **c.** carbohydrates.
   b. mitochondria. **d.** ribosomes.

8. What is the function of a ribosome?

Think Critically

9. **Infer** The pancreas is an organ found in many animals. It makes enzymes that are used by other parts of the digestive system. Enzymes are proteins that help speed up reactions in the body. Which type of cell structure(s) might produce those enzymes? Explain your answer.

10. **Classify** For each of the following, tell whether the structure is found only in eukaryotes or in both eukaryotes and prokaryotes: cell membrane, mitochondria, ribosome, Golgi apparatus, nucleus, cytoplasm, and DNA.

7.3 Cell Transport

Understand Key Concepts

11. The movement of water molecules across a membrane that does not let all materials pass through it is known as
    a. exocytosis. **c.** endocytosis.
    b. pumping. **d.** osmosis.

12. Can other substances besides water undergo osmosis? Explain.

Think Critically

13. **Apply Concepts** What would happen to a sample of your red blood cells if they were placed in a hypotonic solution? Explain.

7 CHECK Understanding

7.4 Homeostasis and Cells

Understand Key Concepts

14. Which of the following is true of ALL single-celled organisms?

a. They are all prokaryotes.

b. They are all bacteria.

c. They all reproduce.

d. They all have a nucleus.

Think Critically

15. Infer Would you expect skin cells to contain more or less mitochondria than muscle cells? Explain your answer.

16. Infer Artificial pacemakers are devices that help keep heart muscle cells contracting at a steady rate. If a person needs an artificial pacemaker, what does that mean about his or her heart cells' ability to send and receive signals?

Connecting Concepts

Use Science Graphics

Use the data table to answer questions 17 and 18.

Cell Sizes

Cell	Approximate Diameter
Escherichia coli (bacterium)	0.5–0.8 μm
Human erythrocyte (red blood cell)	6–8 μm
Human ovum (egg cell)	100 μm
Saccharomyces cerevisiae (yeast)	5–10 μm
Streptococcus pneumoniae (bacterium)	0.5–1.3 μm

17. Classify Tell whether each of the cells listed is prokaryotic or eukaryotic.

18. Infer *Chlamydomonas reinhardtii* is a single-celled organism with an approximate diameter of 10 μm. Based on the information given here, do you think it is a prokaryote or a eukaryote? Explain your answer.

solve the CHAPTER MYSTERY

DEATH BY…WATER?

During the race, Michelle drank plenty of water. However, she didn't replace the salts she lost in her sweat. As a result, her blood became hypotonic. Osmotic pressure led the cells in her brain (and throughout her body) to swell.

As Michelle's blood became less concentrated, cells in her brain sent chemical signals to her kidneys to stop removing salts from her bloodstream. However, she continued to sweat. Sweating caused her to continue to lose salt through her skin.

By the end of the race, Michelle had lost a lot of salt and minerals. She had taken in so much water that homeostasis had broken down. Her cells were damaged by osmotic pressure that was unbalanced.

When Michelle went to the hospital, the doctors found that she had hyponatremia, or water intoxication. Left untreated, this condition can lead to death.

1. Relate Cause and Effect When a person sweats, water and salts are lost from the body. Michelle drank water but did not replace salts. How did this affect her cells?

2. Infer Imagine that Michelle drank both water and sports drinks containing the salts she lost. Do you think she would have felt better or worse? Explain.

3. Infer Do you think that hyponatremia happens because of osmosis or active transport? Explain your reasoning.

UntamedScience **Never Stop Exploring Your World.** Michelle's mysterious illness is just the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. Animal cells have all of the following EXCEPT
- **A** mitochondria.
- **B** chloroplasts.
- **C** a nucleus.
- **D** a cell membrane.

2. The nucleus includes all of the following structures EXCEPT
- **A** cytoplasm.
- **B** a nuclear envelope.
- **C** DNA.
- **D** a nucleolus.

3. The human brain is an example of a(n)
- **A** cell.
- **B** tissue.
- **C** organ.
- **D** organ system.

4. Which cell structures are sometimes found attached to the endoplasmic reticulum?
- **A** chloroplasts
- **B** nuclei
- **C** mitochondria
- **D** ribosomes

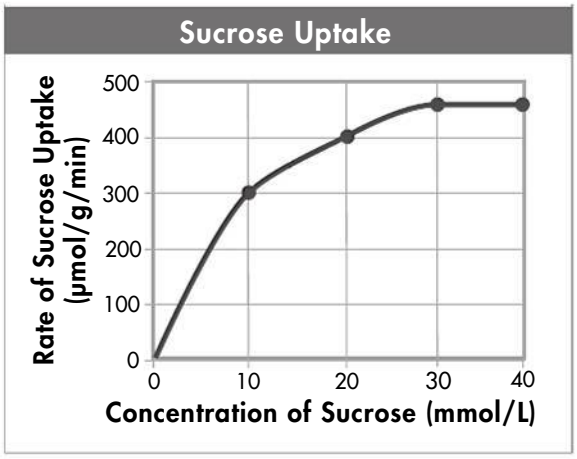
5. Which process always involves the movement of materials from inside the cell to outside the cell?
- **A** diffusion
- **B** exocytosis
- **C** endocytosis
- **D** osmosis

6. Which of the following is an example of active transport?
- **A** facilitated diffusion
- **B** osmosis
- **C** diffusion
- **D** endocytosis

7. The difference between prokaryotic and eukaryotic cells involves the presence of
- **A** a nucleus.
- **B** genetic material in the form of DNA.
- **C** chloroplasts.
- **D** a cell membrane.

Questions 8 and 9

In an experiment, scientists placed plant cells in solutions that had different concentrations of the sugar sucrose. Then the scientists measured the rate at which the cells absorbed sucrose from the solution. The results are shown in the graph below.



8. The graph shows that overall, sucrose
- **A** cannot be absorbed by plant cells.
- **B** uptake increased as concentration increased.
- **C** uptake decreased as concentration increased.
- **D** uptake stayed the same as concentration increased.

9. Based on the graph, the rate of sucrose uptake
- **A** increased at a constant rate from 0 to 30 mmol/L.
- **B** decreased at varying rates from 0 to 30 mmol/L.
- **C** was less at 25 mmol/L than at 5 mmol/L.
- **D** was constant between 30 and 40 mmol/L.

Open-Ended Response

10. What would you expect to happen if you placed a typical cell in fresh water?

If You Have Trouble With . . .

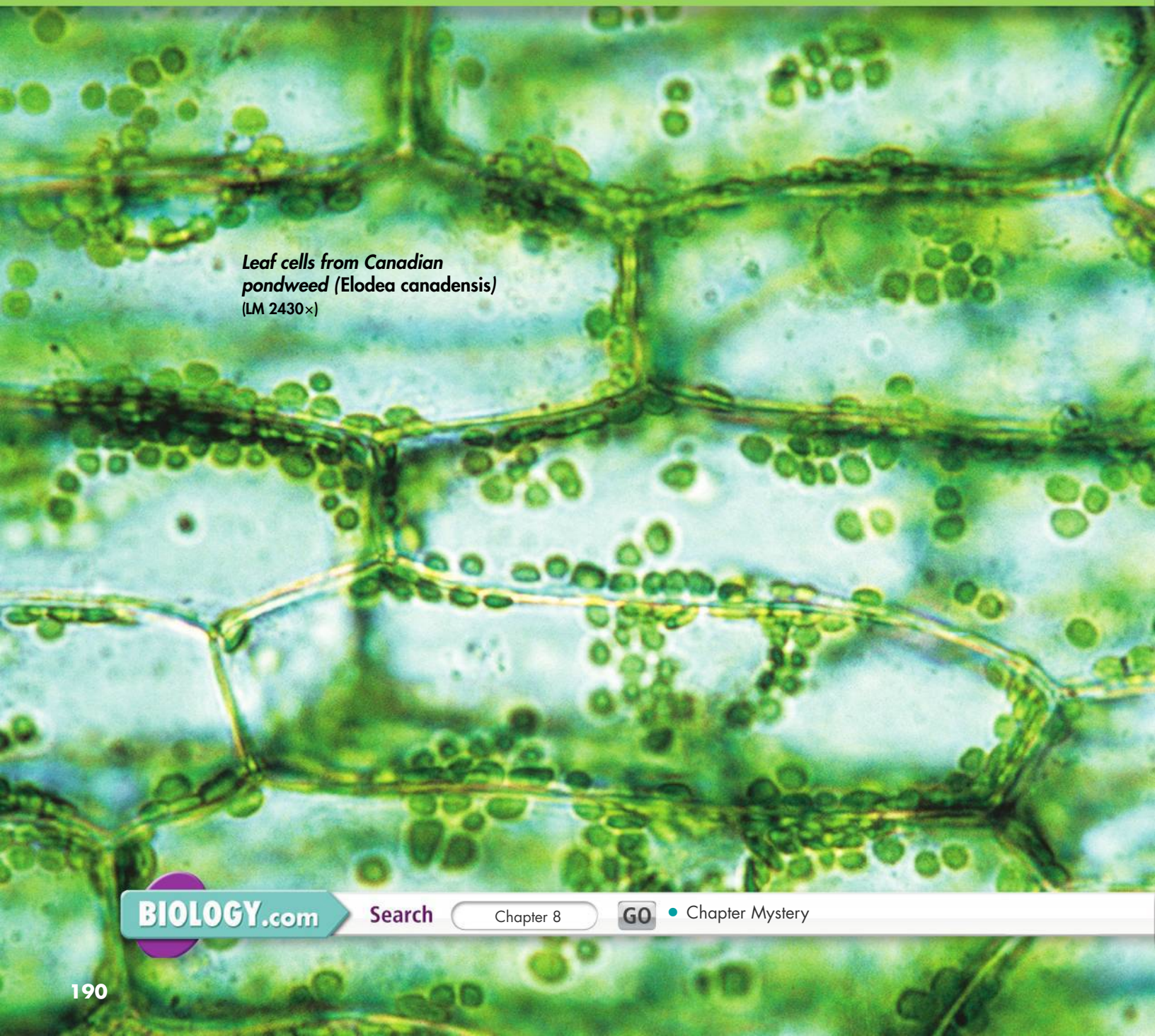
Question	1	2	3	4	5	6	7	8	9	10
See Lesson	7.2	7.2	7.4	7.2	7.3	7.3	7.1	7.3	7.3	7.3

8 Photosynthesis

Big idea

Cellular Basis of Life

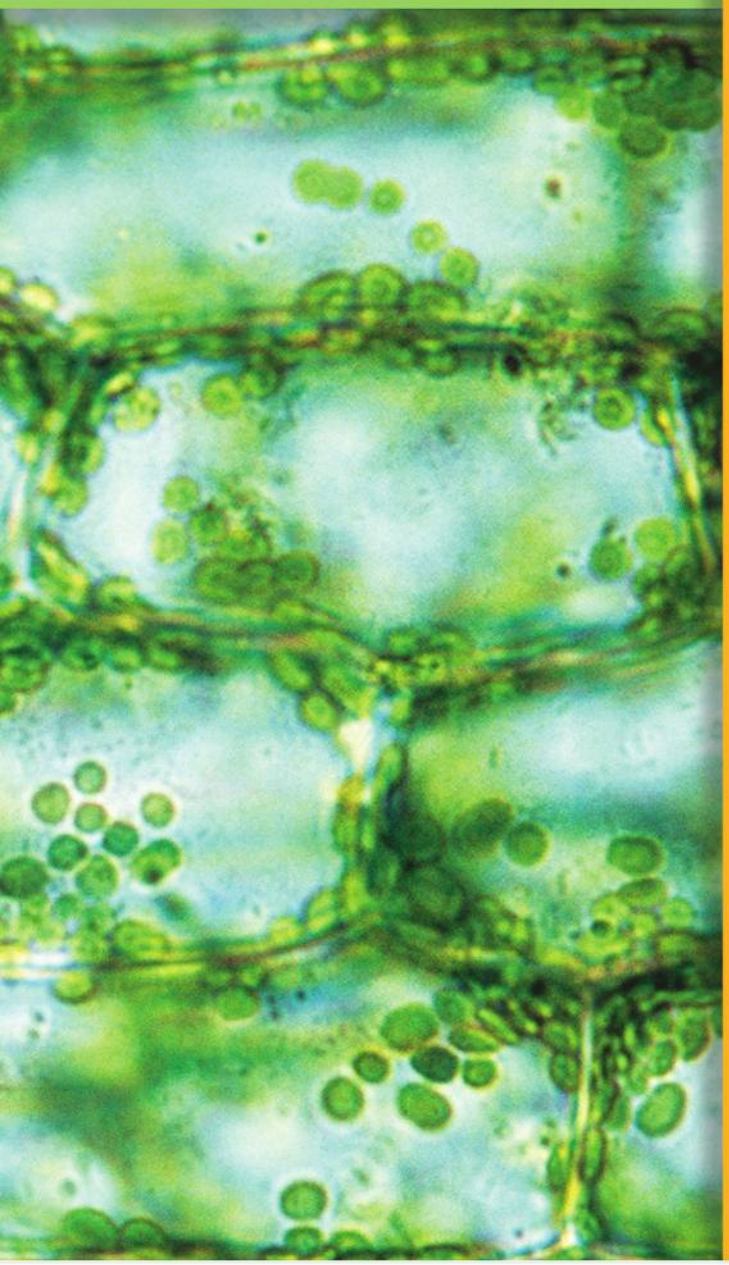
Q: How do plants and other organisms capture energy from the sun?



***Leaf cells from Canadian pondweed* (Elodea canadensis)**
(LM 2430×)

BIOLOGY.com Search Chapter 8 GO • Chapter Mystery

INSIDE:



- Untamed Science Video
- Flash Cards

CHAPTER MYSTERY

OUT OF THIN AIR?

When a tiny seed grows into a huge tree, where does all the extra mass come from? More than 300 years ago, a Flemish doctor named Jan van Helmont decided to find out. He chose a young willow tree that weighed just 2 kilograms. He planted it in a pot with 90 kilograms of dry soil and placed it in bright sunlight. He watered the plant as needed. Five years later, he took the tree from the pot and weighed it. It weighed about 77 kilograms. Where did the extra 75 kilograms come from? Did it come from the soil, the water—or right out of thin air?

Read for Mystery Clues As you read this chapter, look for clues to help you discover where the willow tree's extra mass came from. Then, solve the mystery at the end of the chapter.

FOUNDATIONS for Learning

Plant cells use light energy to make useful chemicals. These reactions take place in special parts of the cell. Before you read the chapter, label index cards with the words *water*, *carbon dioxide*, *oxygen*, *sugars*, and *light*. Label one sheet of paper as shown. At the end of the chapter are two activities that use the cards and sheets of paper to help answer the question: How do plants and other organisms capture energy from the sun?

8.1 Energy and Life

Key Questions

- ***Why is ATP useful to cells?***
- ***What happens during photosynthesis?***

BUILD Understanding

Compare/Contrast Table As you read, create a table that compares autotrophs and heterotrophs. Think about how they get energy. Include in your table a few examples of each type of living thing.

In Your Workbook Go to your workbook to learn more about making a compare/contrast table. Complete the compare/contrast table for Lesson 8.1.

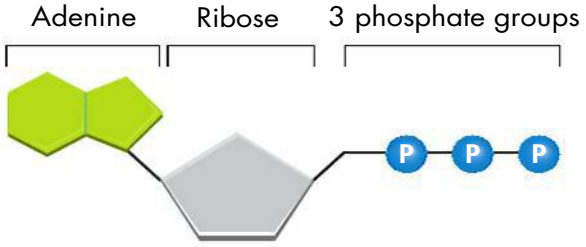
Chemical Energy

Energy is the ability to do work. Nearly everything you do takes energy. Lights, radios, and computers all use electrical energy to run. When you toast marshmallows on a campfire, you are using heat energy to warm the food. A car runs on fuel—the chemical energy in gasoline. All these things need energy to work.

Living things need energy, too. It takes plenty of energy to play soccer or other sports. Sometimes it is not as easy to tell that something uses energy. Did you know that even when you are sleeping, your cells are busy using energy? They are using energy to build new molecules and get rid of wastes. Without the ability to get and use energy, cells would die.

Energy Changes Form Light, heat, and electricity are just three forms of energy. Chemical energy is another form of energy. Chemical energy is the energy stored in chemical bonds. Energy can change from one form to another. When you light a candle, the wax burns. Chemical bonds between carbon and hydrogen atoms in the wax are broken. New bonds form between these atoms and oxygen from the air. What you get are new molecules of carbon dioxide and water. The bonds in the new molecules store less energy than before. The extra chemical energy that came from the old bonds changes form. The extra energy becomes the heat and light given off by the candle's flame.

ATP Living things use chemical energy. One of the most important chemicals that cells use to store and give off energy is called **adenosine triphosphate** (uh DEN uh seen try FAHS fayt). It's known as **ATP** for short. ATP is made up of adenine, a sugar called ribose, and three phosphate groups. The phosphate groups are the key to why ATP can store and release energy.



ATP ATP is the basic energy source used by all types of cells.

Storing Energy Adenosine diphosphate (ADP) is similar to ATP. However, ADP has only two phosphate groups instead of three. This difference is the key to how living things store energy. When a cell has extra energy, it can store small amounts of it by adding a phosphate group to ADP molecules, which turns ADP to ATP.

Releasing Energy Cells can give off the energy stored in ATP by breaking the chemical bonds between the second and third phosphate groups. A cell can add or subtract these phosphate groups whenever it needs to store or use energy.

Key Question Why is ATP useful to cells?
ATP can easily release and store energy by breaking and re-forming the bonds between its phosphate groups.

Using Chemical Energy Cells use ATP in many ways. For example, cells use it to power active transport. ATP provides the energy needed to move material into and out of many cells. ATP also helps proteins in muscles to slide closer together. This motion makes muscles flex. Cells that crawl, twist, and swim depend on ATP as well. Energy from ATP powers many other important events, such as the making of proteins and responses to chemical signals outside of the cell.

Short-Term Storage ATP is so useful that you might think cells would be packed with it. In fact, most cells have only a small amount—enough to last for a few seconds of activity. The reason is that ATP is great for giving off a small amount of energy very quickly. But, it is not good for storing large amounts for a long time. The sugar glucose is much better for energy storage. A single glucose molecule stores more than 90 times the energy of a molecule of ATP. So, it makes sense for cells to store energy in the form of glucose. Cells can then use the stored glucose to make ATP and ADP as needed.

ATP Comes From Food

Once cells use up their supply of ATP, they must somehow make more of it. So, where do living things get the energy they use to make ATP? The simple answer is that it comes from the chemical compounds that we call food. But, different living things get their food from different sources.

BUILD Vocabulary

adenosine triphosphate (ATP) one of the principal chemical compounds that living things use to store and release energy

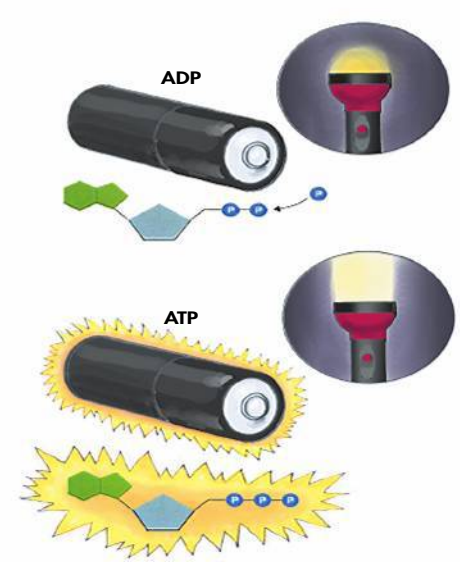
PREFIXES

The prefix *di-* means "two" and the prefix *tri-* means "three." A molecule of adenosine *tri*phosphate (ATP) has three phosphate groups, while adenosine *di*phosphate (ADP) has only two.

BUILD Connections

MOLECULAR BATTERY

When a phosphate group is added to an ADP molecule, it makes ATP. ADP has some energy, but not as much as ATP. ADP is like a partially charged battery. It can be fully charged by adding a phosphate group.



In Your Workbook Go to your workbook to learn more about how an ATP molecule stores energy.

BUILD Vocabulary

heterotroph
a living thing that gets food by consuming, or eating, other living things

autotroph
a living thing that can capture energy from sunlight or chemicals to make its own food

photosynthesis
the process by which plants and other autotrophs use light energy to convert water and carbon dioxide into oxygen and high-energy carbohydrates such as sugars and starches

WORD ROOTS

Photosynthesis comes from the Greek words *photo*, meaning "light," and *synthesis*, meaning "putting together." Thus, *photosynthesis* means "using light to put something together."

Heterotrophs Eat Food Living things that get food by eating other living things are known as **heterotrophs.** Some heterotrophs get their food by eating plants, such as grasses. Others, such as the cheetah shown at right, get food by eating other animals. Still other heterotrophs—mushrooms, for example—get food by breaking down the tissues of dead things.

Autotrophs Make Food The energy in nearly all food molecules first came from the sun. Plants, algae, and some bacteria can use light energy from the sun to make their own food. Living things that make their own food are called **autotrophs.** All life on Earth depends on autotrophs to get energy from sunlight and store it in the molecules that make up food. The process by which autotrophs use the energy of sunlight to produce high-energy carbohydrates—sugars and starches—that can be used as food is known as **photosynthesis.**

Key Question What happens during photosynthesis?

During photosynthesis, plants change the energy of sunlight into chemical energy stored in the bonds of carbohydrates.

Autotrophs and Heterotrophs Grass uses sunlight to make food. Cheetahs, in turn, get their energy by eating organisms who eat the grass.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. An animal that gets its food by eating other animals is a(n) _____.
2. _____ provides a cell with energy when it loses a phosphate group.
3. _____ use photosynthesis to make sugars.

Critical Thinking

4. **Explain** Why are decomposers, such as mushrooms, heterotrophs and not autotrophs?

5. **Write to Learn** Answer the first clue of the mystery. In your answer explain how autotrophs get food and how that might lead to an increase in mass.

MYSTERY CLUE

Like all plants, the willow tree van Helmont planted was an autotroph. How might its ability to use the sun's energy to make food help it gain mass? (Hint: See p. 193.)

BIOLOGY.com Search Lesson 8.1 GO • Lesson Assessment

8.2 Photosynthesis: An Overview

Chlorophyll and Chloroplasts

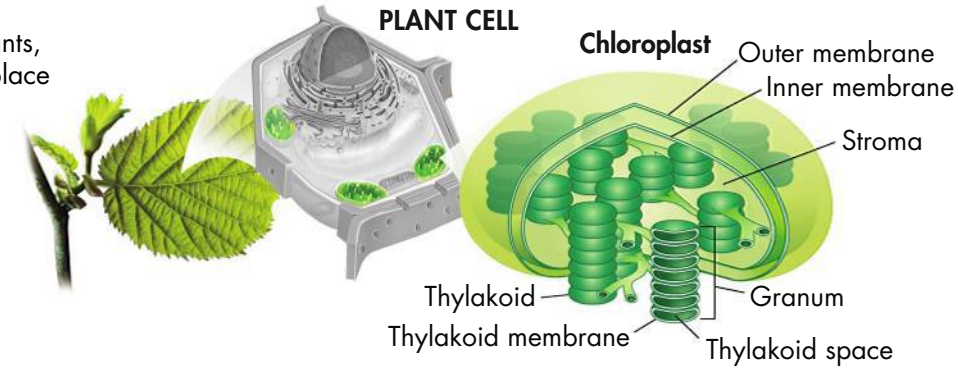
Our lives, and the lives of nearly every living thing on Earth, depend on the sun and photosynthesis. For photosynthesis to take place, autotrophs must capture light energy from the sun.

Light Energy from the sun travels to Earth in the form of light. Sunlight, which our eyes see as "white" light, is actually a mixture of different wavelengths. Many of these wavelengths are visible to our eyes. Our eyes see the different wavelengths of visible light as different colors: shades of red, orange, yellow, green, blue, indigo, and violet.

Pigments Plants gather the sun's energy with light-absorbing molecules called pigments. The most important pigment in plants is chlorophyll (KLAWR uh fil). Out of all the different colors of light, the chlorophyll found in plants absorbs blue-violet light and red light the best. Chlorophyll does not absorb green light very well. Leaves look green because they reflect green light.

Key Question What role do pigments play in the process of photosynthesis?
Living things that carry out photosynthesis use pigments to get energy from sunlight.

Chloroplasts Photosynthesis takes place inside organelles called chloroplasts. These organelles hold many flat, bag-shaped membranes called **thylakoids** (THY luh koydz). Thylakoids are connected to one another and arranged in stacks. These stacks are called grana. Chlorophyll and other pigments are found in these thylakoid membranes. The liquid-filled space around the thylakoids is known as the **stroma.** You can see what makes up a chloroplast in the picture below.



The Chloroplast In plants, photosynthesis takes place inside chloroplasts.

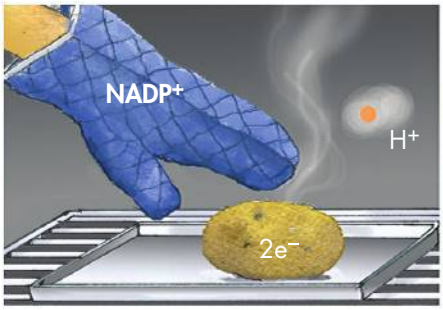
Key Questions

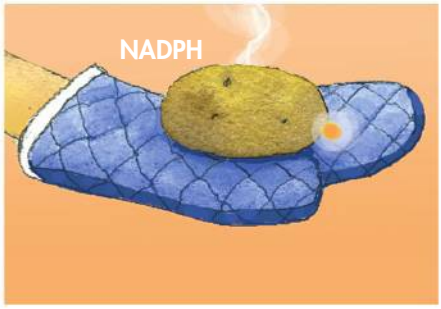
- ***What role do pigments play in the process of photosynthesis?***
- ***What are electron carrier molecules?***
- ***What are the reactants and products of photosynthesis?***

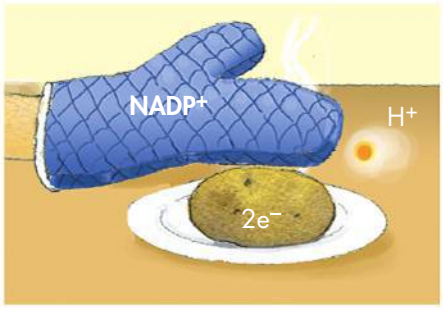
BUILD Understanding

KWL Chart Make a chart with three columns labeled What I **K**now, What I **W**ant to Know, and What I **L**earned. Before you read the lesson, fill in the first two columns. Complete the last column as you read the lesson.

In Your Workbook Go to your workbook to learn more about making a KWL chart. Complete the KWL chart for Lesson 8.2.







BUILD Connections

CARRYING ELECTRONS

$NADP^+$ is a carrier molecule that transports pairs of high-energy electrons (and an H^+ ion). Compare its role to that of an oven mitt used to transport a hot baked potato.

BUILD Vocabulary

thylakoid
a baglike photosynthetic membrane found in chloroplasts

stroma
the liquid-filled space surrounding the thylakoids in chloroplasts

$NADP^+$
one of the molecules that accepts high-energy electrons from chlorophyll and carries them to other molecules during photosynthesis

light-dependent reaction
a reaction of photosynthesis that uses ATP, NADPH, and carbon dioxide to make high-energy sugars

light-independent reaction
a reaction of photosynthesis that uses light energy to make ATP and NADPH

CHEMICAL NAMES

When a plus sign appears in a chemical name, it means the chemical has a positive charge and can accept electrons.

High-Energy Electrons

Light is a form of energy. Anything that absorbs light takes in energy. When chlorophyll takes in light, much of that energy is moved directly to electrons in the chlorophyll. The energy levels of the electrons go up. A stream of these high-energy electrons is what makes photosynthesis work.

These high-energy electrons cannot keep their energy for long on their own. They need a special carrier. Plant cells use molecules to carry high-energy electrons from chlorophyll to other places. One of these carrier molecules is **$NADP^+$** (nicotinamide adenine dinucleotide phosphate). It accepts and holds two high-energy electrons, along with a hydrogen ion (H^+). This process changes $NADP^+$ into NADPH. The NADPH carries the electrons to other parts of the cell. There, the electrons and their energy can be used to help build useful molecules, such as sugars.

Key Question What are electron carrier molecules?
Electron carrier molecules are compounds that can transfer a pair of high-energy electrons, along with most of their energy, to another molecule.

A Summary of Photosynthesis

Photosynthesis has many steps. It usually has 6-carbon sugars ($C_6H_{12}O_6$) as the final product. All of the steps of photosynthesis can be summed up in the following equation:

In Symbols:

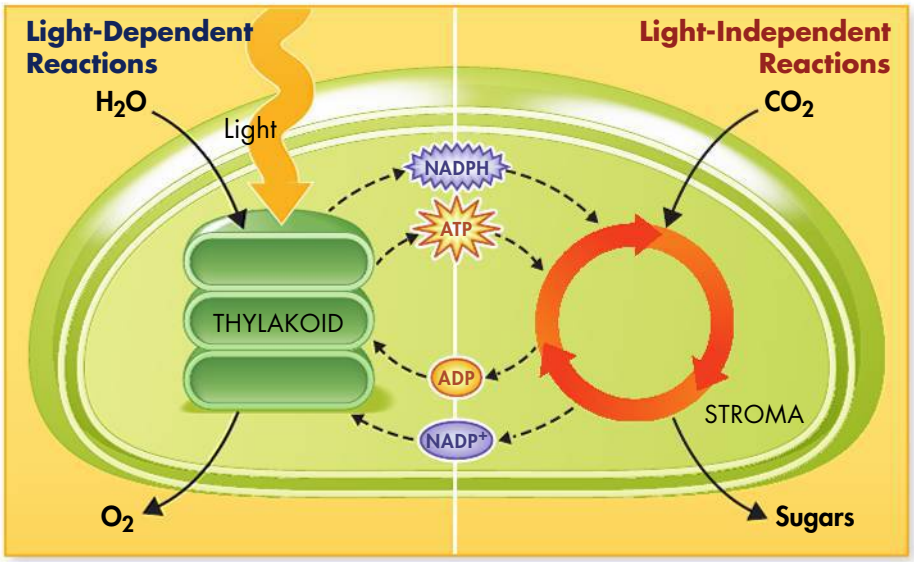
$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$$

In Words:

Carbon dioxide + Water $\xrightarrow{\text{light}}$ Sugars + Oxygen

Plants use the sugars from photosynthesis to make other carbohydrates, such as starches. The sugars are also used to make other compounds, such as proteins and lipids.

Key Question What are the reactants and products of photosynthesis?
Photosynthesis uses light energy to change water and carbon dioxide (reactants) into sugars and oxygen (products).



The Stages of Photosynthesis There are two stages of photosynthesis: light-dependent reactions and light-independent reactions.

Light-Dependent Reactions The equation for photosynthesis looks simple, but that is because it does not show all of the smaller steps. In fact, there are two sets of reactions. The first set is the **light-dependent reactions.** They take place in the thylakoids. These reactions need light and light-absorbing pigments to take place. They use energy from sunlight and electrons and hydrogen ions from water to make high-energy ATP and NADPH. Oxygen gas, the oxygen we breathe every day, is also released.

Light-Independent Reactions The second set of reactions in photosynthesis is called the **light-independent reactions.** In this set, plants use the ATP and NADPH made in the light-dependent reactions. They make high-energy sugars out of carbon dioxide from the air. Light-independent reactions do not need light. They take place in the stroma.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. The set of reactions that takes place in the stroma are called the _____.
2. The light-dependent reactions need _____, a carrier molecule that is able to accept high-energy electrons and a hydrogen ion.

Critical Thinking

3. Describe the overall process of photosynthesis. Include the reactants and the products.

4. **Write to Learn** Answer the second clue of the mystery. Think about the things that plants need for photosynthesis. Which of these things might cause the plant to gain mass?

MYSTERY CLUE

Van Helmont concluded that water must have supplied the extra mass gained by the tree. In fact, he had only half of the answer. What photosynthesis reactant was he missing in his conclusion? (Hint: See p. 196.)

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What Waste Product Is Produced During Photosynthesis?

What is a waste product? It is like garbage in your kitchen. You may eat the food that comes out of a jar, but your body cannot use the jar. The empty jar is a waste product. But you might be able to use the jar for something else, like storing leftover soup. During many reactions, cells make waste products as well as needed products. Sometimes these waste products cannot be used by the cell at all. At other times, the waste product is used in another part of the cell or by other cells. In this activity, you will study photosynthesis in a water plant called *Elodea*. You will see one product of photosynthesis. You will decide if it is a waste product for this plant.

1. Fill a clear, plastic cup halfway with sodium bicarbonate solution. This solution has carbon dioxide in it.
2. **a.** Place a piece of plant in a test tube. Make sure that the cut part of the plant is at the bottom.
   b. Add sodum bicarbonate solution. **CAUTION:** *Be careful with glass.*
3. **a.** Hold your finger over the open end of the test tube.
   b. Turn the test tube over. Lower it to the bottom of the cup. Make sure no air is inside the test tube.
4. Place the cup in bright light.
5. Wait 20 minutes.
6. Look closely at the leaves. Write down what you see.

Analyze and Conclude

1. Observe What did you see on the plant's leaves?

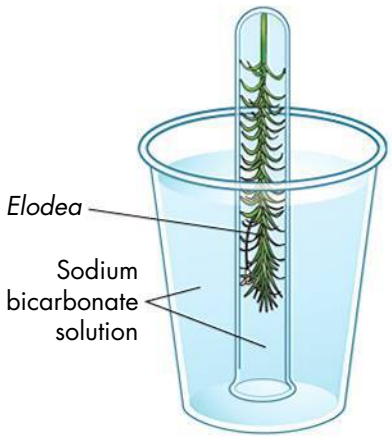
2. Infer Think about the products of photosynthesis. What do you think formed on the leaves of the plant? How do you know?

3. Draw Conclusions Do you think that the product that formed on the leaves is a waste product? Explain.

4. Infer Think about the reactants of photosynthesis. What do you think happened to the carbon dioxide in the sodium bicarbonate solution?

5. Apply Concepts Which plant organelle carries out photosynthesis? How can you tell that this plant's cells have that organelle?

In Your Workbook Get more help for this activity in your workbook.



8.3 The Process of Photosynthesis

The Light-Dependent Reactions: Making ATP and NADPH

Remember that the steps of photosynthesis are divided into two sets. They are the light-dependent reactions and the light-independent reactions. The light-dependent reactions cannot take place in the dark. They are the reason that plants need light.

The light-dependent reactions take place in the thylakoids of chloroplasts. These baglike membranes hold groups of chlorophyll and proteins known as **photosystems.** Photosystems take in sunlight and use it to add energy to electrons. These electrons are passed to a set of carriers in the thylakoid membrane. There are two photosystems, and they are named in order of their discovery—not in the order that they do their work.

Photosystem II The pigments of photosystem II absorb light energy and release high-energy electrons. These electrons then get passed down the **electron transport chain.** This chain is a group of carrier proteins. They use energy from the electrons to pump H^+ ions inside the thylakoid.

As light shines on chlorophyll, more and more electrons enter the electron transport chain. Chlorophyll gets new electrons when enzymes break up water molecules (H_2O). As plants take electrons from water, oxygen and hydrogen are left behind. The oxygen goes into the air that we breathe. The hydrogen becomes ions that are left inside the thylakoid.

ATP Formation In photosystem II, hydrogen ions build up inside the thylakoid. Some of these ions come from water breaking up. Others come from the electron transport chain. The building up of H^+ ions inside the thylakoid makes the outside of the thylakoid more negatively charged than the inside. This difference in charge and number of H^+ ions on either side of the membrane is what powers the making of ATP.

H^+ ions cannot cross the membrane directly. Instead, they pass through a protein called ATP synthase that is like a revolving door in the membrane. The buildup of H^+ ions on one side causes them to pass through ATP synthase and force it to turn. As it turns, it adds a phosphate group to ADP to make ATP.

Key Questions

- ***What happens during the light-dependent reactions?***
- ***What happens during the light-independent reactions?***
- ***What factors affect photosynthesis?***

BUILD Understanding

Flowchart As you read, create a flowchart that clearly shows the steps of the light-dependent reactions.

In Your Workbook Go to your workbook to learn more about making a flowchart. Complete the flowchart for Lesson 8.3.

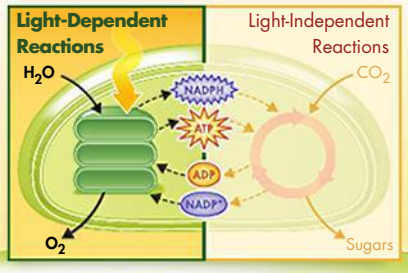
Photosystem I The electrons from photosystem II lost energy when they pumped ions across the membrane. In photosystem I, light gives them energy again. Then, they go through another electron transport chain. Here, they are used to make $NADP^+$ into NADPH, which goes on to the next set of reactions.

Summary of Light-Dependent Reactions The light-dependent reactions give off oxygen gas. They also make ATP and NADPH. These compounds are important for the cell. They provide the energy needed to build sugars in the light-independent reactions.

Key Question What happens during the light-dependent reactions?

The light-dependent reactions use water and energy from sunlight to make oxygen and change ADP and $NADP^+$ into the energy carriers ATP and NADPH.

Light-Dependent Reactions
The light-dependent reactions of photosynthesis take place in the thylakoids of the chloroplast. They use energy from sunlight to produce ATP, NADPH, and oxygen.



CYTOPLASM

$2H^+ + 2\ NADP^+ + 4e^- \rightarrow 2\ NADPH$ → To Light-Independent Reactions

H^+

ATP → To Light-Independent Reactions

ADP + P

ATP synthase

STROMA

Light

Light

H^+

Thylakoid membrane

Electron carriers

Photosystem I

Photosystem II

$4e^-$

$2\ H_2O \rightarrow 4H^+ + O_2$

H^+

THYLAKOID

Photosystem II
Light shining on pigments energizes electrons that come from water.

Electron Transport
High-energy electrons move down the chain, which pumps H^+ ions to inside of the thylakoid.

Photosystem I
Electrons are reenergized with more light.

Electron Transport
The reenergized electrons are transferred to $NADP^+$, to make NADPH.

ATP Formation
Excess H^+ ions spill out through ATP synthase. The protein rotates as each ion passes through, which changes ADP to ATP.

BIOLOGY.com Search Lesson 8.3 GO • Art in Motion

Seeing Green The color green of most plants is caused by the reflection of green light by the pigment chlorophyll.

Light-Independent Reactions: Making Sugars

The ATP and NADPH made by the light-dependent reactions store a lot of chemical energy. However, they are not very stable. They last only a few minutes. During the light-independent reactions—also called the Calvin cycle—plants build high-energy sugars. These sugars are stable, so they can store energy for a long time. The Calvin cycle is named after the American scientist Melvin Calvin.

Carbon Dioxide Enters the Cycle One of the reactants of the Calvin cycle is carbon dioxide. It comes from the air around a plant. An enzyme joins carbon dioxide molecules with molecules that are already in the cell. Then, one chemical step at a time, the cycle produces energy-rich carbohydrates. These steps use energy from ATP and NADPH.

Sugar Production With each turn of the cycle, a few energy-rich carbohydrate molecules leave the cycle. This is the step that makes the Calvin cycle important. These molecules become the building blocks that the plant cell uses to make sugars, lipids, amino acids, and other compounds. The plant will use these compounds as the food and building materials it needs to grow.

The rest of the higher-energy molecules stay in the cycle. Enzymes use ATP to change them to molecules that will join with new carbon dioxide molecules. Then, the cycle begins again.

Summary of Light-Independent Reactions The Calvin cycle uses compounds made in the light-dependent reactions and carbon dioxide from the air to make sugars. The plant uses the sugars to meet its energy needs and to build molecules needed for growth. When other living things eat plants, they, too, get the energy they need.

Key Question What happens during the light-independent reactions?

During the light-independent reactions, ATP and NADPH are used to make high-energy sugars.

BUILD Vocabulary

photosystem
the light-collecting units of the chloroplast

electron transport chain
a series of proteins in which high-energy electrons are used to change ADP to ATP

WORD ROOTS

The Greek word *photo* means "light." A photosystem is a system of pigment molecules that collects energy from light.

The End Results The two parts of photosynthesis work together. The light-dependent reactions change the energy of sunlight into chemical energy. The light-independent reactions use that energy to make sugars from carbon dioxide and water. Both plants and animals use the sugars and oxygen from photosynthesis to live and grow.

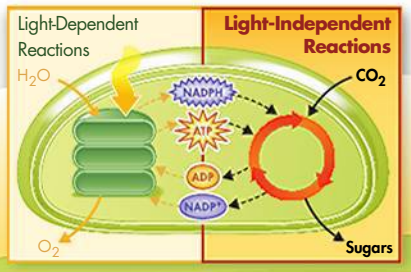
Factors Affecting Photosynthesis

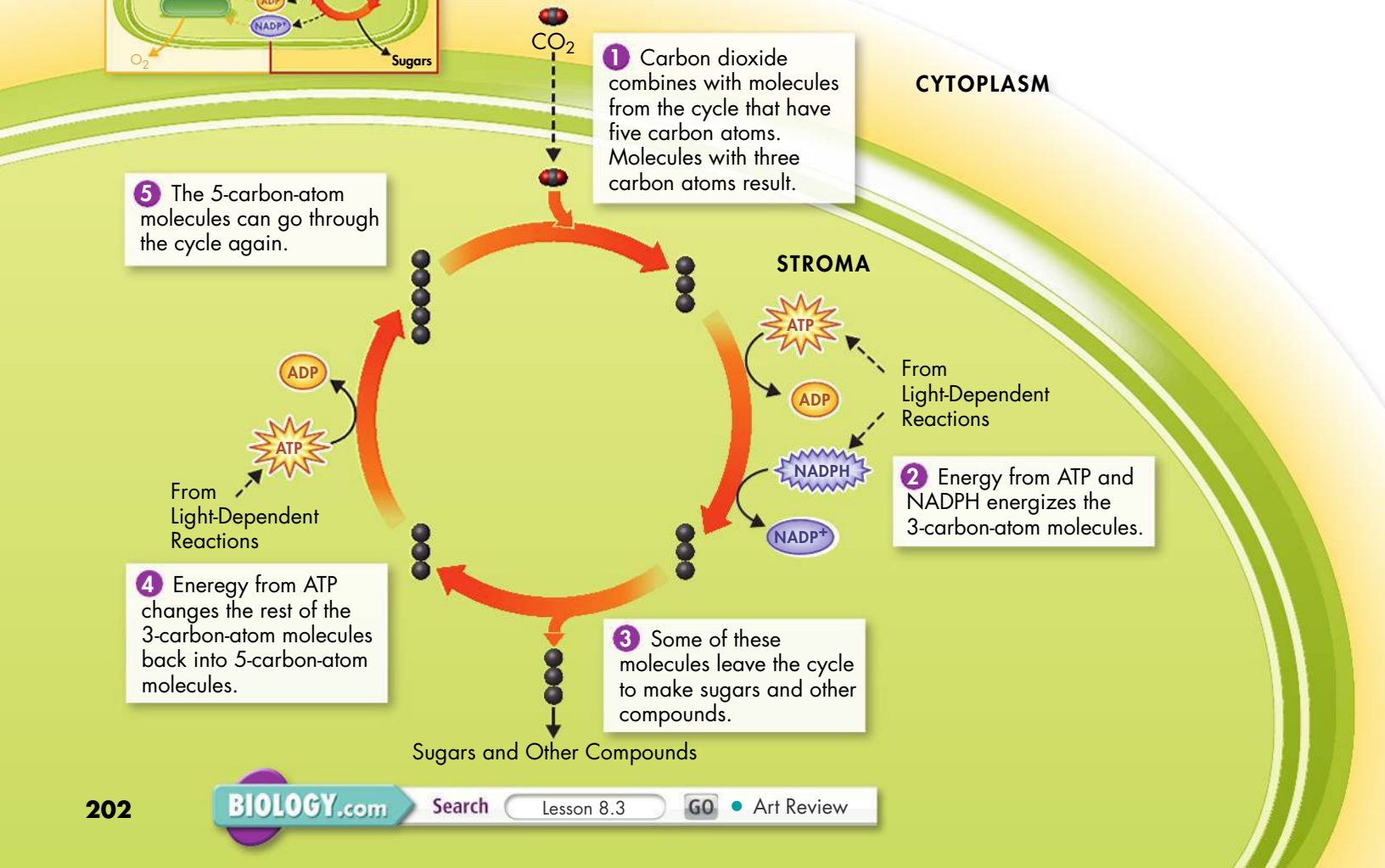
Temperature, Light, and Water Photosynthesis can speed up or slow down depending on several factors. Temperature is one factor that can affect the rate of photosynthesis. Photosynthesis enzymes work best between 0°C and 35°C. Light intensity is another factor. Very bright light speeds up photosynthesis. Water levels also affect the rate of photosynthesis.

Key Question What factors affect photosynthesis?

Three important factors that affect photosynthesis are temperature, light intensity, and the availability of water.

Light-Independent Reactions The light-independent reactions of photosynthesis take place in the stroma. They use ATP and NADPH from the light-dependent reactions to make high-energy sugars.





Photosynthesis in Extreme Conditions Plants lose water through the tiny openings in their leaves that let in carbon dioxide. When it is hot, most plants close these openings to keep from drying out. But, doing so means less carbon dioxide enters, which slows photosynthesis. Some plants that live in dry, sunny areas have special ways to save water and still carry out photosynthesis.

C4 Plants C4 plants have a special chemical pathway that gets carbon into the Calvin cycle even when there is not much carbon dioxide available. The pathway uses extra ATP but lets the plants carry out photosynthesis when it is hot. Corn and sugar cane are examples of C4 plants.

CAM Plants CAM plants save water by taking air into their leaves only at night. In the dark, carbon dioxide is used to make acids. During the day, these acids are turned back into carbon dioxide for photosynthesis. Some examples of CAM plants are pineapple trees, many desert cacti, and ice plants.

CAM Plants Plants like this ice plant can survive in dry places. The leaves let in carbon dioxide only at night, minimizing water loss.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Energy produced by the _____ is used to pump hydrogen ions from the stroma to the inside of the thylakoid.
2. A _____ is a cluster of pigments and proteins that allows plants to absorb light energy and transfer it to electrons.

Critical Thinking

3. **Sequence** Put the following events of the light-dependent reactions in the order in which they occur: photosystem I, photosystem II, making NADPH, and pumping hydrogen ions into the inside of the thylakoid.
4. **Compare and Contrast** List at least three differences between the light-dependent and light-independent reactions of photosynthesis.
5. **Write to Learn** Answer the third clue of the mystery. How would labeling carbon atoms in carbon dioxide tell apart the products of photosynthesis?

MYSTERY CLUE

Melvin Calvin was able to label carbon atoms in carbon dioxide. He used these labeled atoms to show what happens to the carbon that is used during the light-independent reactions. Where does this carbon end up? (Hint: See p. 201.)

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Pre-Lab: Plant Pigments and Photosynthesis

Problem Do red leaves have the same pigments as green leaves?

Materials paper clips, one-hole rubber stoppers, chromatography paper strips, metric ruler, green and red leaves, coin, sheet of paper, large test tubes, test tube rack, glass-marking pencil, 10-mL graduated cylinder, isopropyl alcohol, colored pencils

Lab Manual Chapter 8 Lab

Skills Focus Predict, Analyze Data, Draw Conclusions

Connect to the Big idea Almost all life on Earth depends, directly or indirectly, on energy from sunlight. Photosynthesis is the process in which light energy is captured and converted to chemical energy. Many reactions are required for this conversion, which takes place in the chloroplasts of plant cells. Some of the reactions depend on light and some do not. Plant pigments play a major role in the light-dependent reactions. In this lab, you will use chromatography to compare the pigments in red leaves with those in green leaves.

Background Questions

a. **Compare and Contrast** What do all plant pigments have in common? How are they different?

b. **Review** Why do most leaves appear green?

c. **Review** What property makes chlorophyll so important for photosynthesis?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Design an Experiment** What is the purpose of this lab?

2. **Control Variables** What is the control in this lab?

3. **Design an Experiment** Why must you place a leaf about 2 cm from the bottom of the paper before rubbing the leaf with the coin?

4. **Predict** Will red leaves contain the same amount of chlorophyll as green leaves? Why or why not?

BIOLOGY.com Search Chapter 8 GO

Visit Chapter 8 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Journey to Panama with the Untamed Science crew to discover how CO_2 affects plant growth.

Data Analysis Look at pigment color data in the ocean to find out how marine algae photosynthesize in the blue light available underwater.

Tutor Tube Learn how to sort out the products and reactants in both the light-dependent and light-independent reactions.

Art Review Focus on the thylakoid membrane to review your knowledge of the light-dependent reactions.

InterActive Art Bring the components of photosynthesis together to run an animation.

Art in Motion Watch the steps of the light-dependent reactions in motion at the molecular level.

Visual Analogies Compare ATP production to a charged battery. See how the electron transport chain is like passing a hot potato.

CHAPTER 8 Summary

8.1 Energy and Life

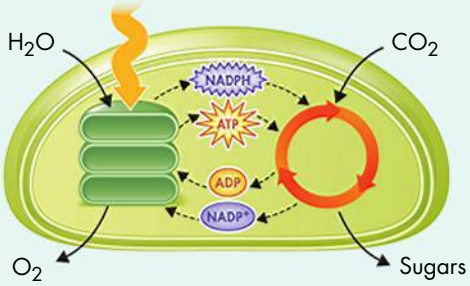
- ATP can easily release and store energy by breaking and re-forming the bonds between its phosphate groups.
- This ability makes ATP very useful as a basic energy source for all cells.
- During photosynthesis, plants change the energy of sunlight into chemical energy stored in the bonds of carbohydrates.

adenosine triphosphate (ATP) (p. 192)
heterotroph (p. 194)
autotroph (p. 194)
photosynthesis (p. 194)

8.2 Photosynthesis: An Overview

- Living things that carry out photosynthesis use pigments to get energy from sunlight.
- An electron carrier is a compound that can transfer a pair of high-energy electrons, along with most of their energy, to another molecule.
- Photosynthesis uses light energy to change water and carbon dioxide (reactants) into sugars and oxygen (products).

thylakoid (p. 195)
stroma (p. 195)
$NADP^+$ (p. 196)
light-dependent reactions (p. 197)
light-independent reactions (p. 197)



8.3 The Process of Photosynthesis

- The light-dependent reactions use energy from sunlight to make oxygen and change ADP and $NADP^+$ into the energy carriers ATP and NADPH.
- During the light-independent reactions, ATP and NADPH are used to make high-energy sugars.
- Three important factors that affect photosynthesis are temperature, light intensity, and the availability of water.

photosystem (p. 199)
electron transport chain (p. 199)

8 CHECK Understanding

Assess the Big idea Cellular Basis of Life

Write an answer to the question below.
Q: How do plants and other organisms capture energy from the sun?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs. To help you begin, read the **Hints** below the questions.

1. **Yeast are single-celled fungi that feed off of sugars in their environment. How do yeast depend on other living things for survival?**

   Hint Many yeast get their food from plants that produce sugars in fruits and saps.

   Hint Yeast are heterotrophs because they rely on other living things to make sugars for them.

2. **How is the function of chlorophyll related to its very specific location within the cell?**

   Hint Chlorophyll absorbs sunlight and transfers its energy to electrons.

   Hint Chlorophyll is found in the thylakoid, where many steps of photosynthesis take place.

3. **The light-independent reactions are sometimes called the "dark reactions" to tell them apart from the light-dependent reactions. Do the steps of the light-independent reactions ever depend on light? Explain.**

   Hint The photosystems need light to energize electrons. These electrons are used to make ATP and NADPH.

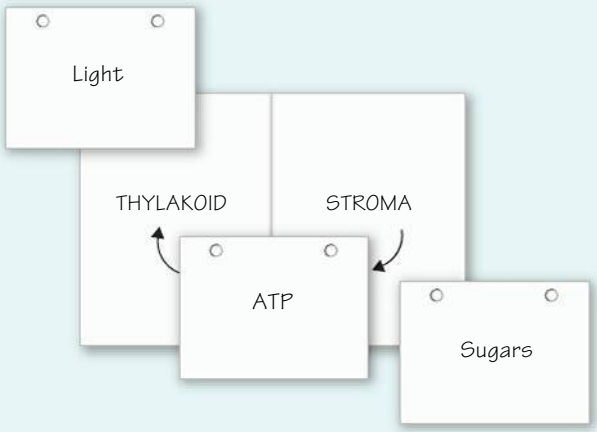
   Hint NADPH and ATP are needed to carry out the light-independent reactions.

Foundations for Learning Wrap-Up

Use the index cards and notebook page you prepared when you started the chapter as a tool to help you organize your thoughts about photosynthesis.

Activity 1 Working with a partner, use the index cards and notebook page to create a diagram to show the two stages of photosynthesis. Then, use the index cards to create a chemical equation that summarizes photosynthesis.

Activity 2 With your partner, label four more index cards with NADPH, ATP, ADP, and $NADP^+$. Using your diagram from Activity 1, add the cards to the diagram in the correct positions to complete the stages of photosynthesis. Draw arrows to show the movement of the molecules between the stages.



8.1 Energy and Life

Understand Key Concepts

1. Which of the following are autotrophs?
   a. deer
   b. grasses
   c. leopards
   d. mushrooms

Test-Taking Tip

Eliminate Incorrect Answers Read all of the answer choices carefully. Even if you are not sure of the correct answer, you may be able to cross out one or two of the answer choices that are incorrect. In question 1, answers **a** and **c** are incorrect because they are animals, and animals are heterotrophs. So, you can eliminate these answer choices.

2. Where do plants get the energy they need to carry out photosynthesis?
   a. air
   b. soil
   c. sunlight
   d. water

3. How does a molecule of ATP compare to a molecule of glucose in terms of the amount of energy stored?

Think Critically

4. **Relate Cause and Effect** How might the disappearance of all autotrophs on Earth affect other living things? Explain.

8.2 Photosynthesis: An Overview

Understand Key Concepts

5. In addition to light and chlorophyll, photosynthesis requires
   a. carbon dioxide and sugars.
   b. carbon dioxide and water.
   c. oxygen and sugars.
   d. oxygen and water.

6. What is the function of $NADP^+$?
   a. It absorbs light.
   b. It is an electron carrier.
   c. It is a light-reflecting pigment.
   d. It acts as long-term energy storage.

7. Some plants have leaves that are bright red. How do red leaves differ from green leaves in the types of light they absorb and reflect?

Think Critically

8. **Predict** Why would a plant grow better in white light than in green light? Explain your answer.

8.3 The Process of Photosynthesis

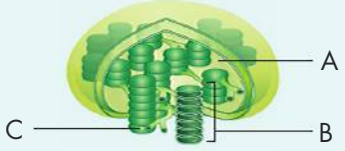
Understand Key Concepts

9. What drives the formation of ATP by ATP synthase?
   a. buildup of H^+ ions
   b. burning oxygen
   c. light absorption
   d. splitting carbon dioxide

10. Which substance from the light-dependent reactions of photosynthesis is a source of energy for the light-independent reactions?
    a. ADP
    b. H_2O
    c. NADPH
    d. pyruvic acid

11. The light-independent reactions of photosynthesis are also known as the
    a. ATP cycle.
    b. Calvin cycle.
    c. carbon cycle.
    d. sugar cycle.

12. Identify the chloroplast parts labeled A, B, and C. In which part(s) do the light-dependent reactions take place? In which part(s) do the light-independent reactions take place?



8 CHECK Understanding

13. Discuss three factors that affect the rate at which photosynthesis takes place. Which steps of photosynthesis are affected by these factors?

Think Critically

14. **Predict** Suppose you water a potted plant and place it by a window in a clear, airtight jar. Predict how the rate of photosynthesis might be affected over the next few days. What might happen if the plant were left there for several weeks?

15. **Form a Hypothesis** Many of the sun's rays may be blocked by dust or clouds formed by volcanic eruptions or pollution. What are some possible short-term and long-term effects of this on plants in an area? On other forms of life?

Connecting Concepts

Use Science Graphics

A water plant placed under bright light gives off bubbles of oxygen. The table below contains the results of an experiment in which the distance from the light to the plant was varied. Use the data table to answer questions 16–18.

Oxygen Production

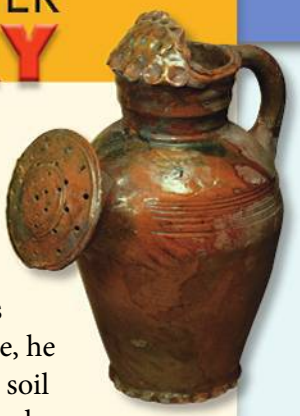
Distance From Light (cm)	Bubbles Produced per Minute
10	39
20	22
30	8
40	5

16. **Graph** Use the data in the table to make a line graph.

17. **Interpret Graphics** Describe the trend in the data. How many bubbles would you predict if the light was moved to 50 cm away? Explain.

18. **Draw Conclusions** What relationship exists between the plant's distance from the light and the number of bubbles produced? What is taking place to cause this relationship? Explain your answer.

solve the CHAPTER MYSTERY



OUT OF THIN AIR?

Most plants grow out of the soil, so you might think that soil adds to plant mass. But, at the end of Jan van Helmont's experiment with the willow tree, he discovered that the mass of the soil was about the same—even though the tree had gained nearly 75 kilograms. Van Helmont decided that the mass must have come from water, because water was the only thing he had added. The tree grew parts that did contain atoms like those found in water, but what van Helmont didn't know was that the new parts also contained carbon. We now know that most of that carbon comes from carbon dioxide in air. Thus, mass comes from two sources: carbon dioxide and water. What form does the added mass take? Think about the origin of the word carbohydrate, from *carbo-*, meaning "carbon," and *hydrate*, meaning "to combine with water," and you have your answer.

1. **Infer** Although soil does not add much to plant mass, how might it help plants grow?

2. **Infer** Imagine that a scientist measures the exact mass of carbon dioxide and water that entered a plant and the exact mass of the sugars produced. Would these masses be identical? Why or why not?

3. **Apply Concepts** What do plants do with all of the sugars they make through photosynthesis? (*Hint:* Plant cells have mitochondria in addition to chloroplasts. What do mitochondria do?)

Untamed Science Finding the solution to the mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. Autotrophs differ from heterotrophs because they
- **A** use oxygen to burn food.
- **B** do not require oxygen to live.
- **C** make carbon dioxide as a product of using food.
- **D** make their own food from carbon dioxide and water.

2. The principal pigment in plants is
- **A** chlorophyll.
- **B** oxygen.
- **C** ATP.
- **D** NADPH.

3. Which of the following is NOT produced in the light-dependent reactions of photosynthesis?
- **A** NADPH
- **B** sugars
- **C** hydrogen ions
- **D** ATP

4. Which of the following correctly summarizes photosynthesis?
- **A** $H_2O + CO_2 \xrightarrow{\text{light}}$ sugars $+ O_2$
- **B** sugars $+ O_2 \xrightarrow{\text{light}} H_2O + CO_2$
- **C** $H_2O + O_2 \xrightarrow{\text{light}}$ sugars $+ CO_2$
- **D** sugars $+ CO_2 \xrightarrow{\text{light}} H_2O + O_2$

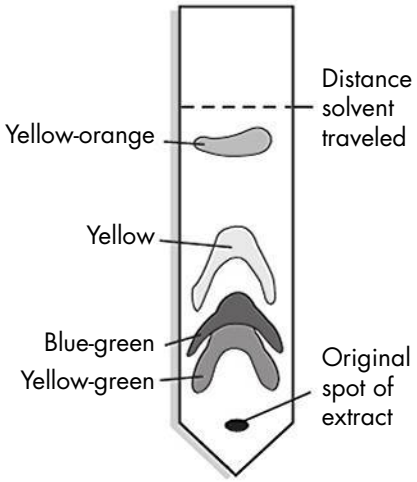
5. The color of light that is LEAST useful to a plant during photosynthesis is
- **A** red.
- **B** blue.
- **C** green.
- **D** violet.

6. The first step in photosynthesis is the
- **A** synthesis of water.
- **B** production of sugars.
- **C** breakdown of carbon dioxide.
- **D** absorption of light energy.

7. In a typical plant, all of the following factors are necessary for photosynthesis EXCEPT
- **A** chlorophyll.
- **B** light.
- **C** oxygen.
- **D** water.

Questions 8–10

A scientist mashes up spinach leaves to make a liquid, or extract, that has lots of pigment in it. She places a drop of the liquid at one end of a strip of paper towel. After the liquid dries, she hangs the paper in a test tube containing alcohol so that only the tip of the paper is in the alcohol. As the alcohol is absorbed and moves up the paper, the different pigments separate as shown below.



8. Which pigment traveled the shortest distance?
- **A** yellow-orange
- **B** yellow
- **C** blue-green
- **D** yellow-green

9. Which of the following is a valid conclusion that can be drawn from this information?
- **A** Spinach leaves use only chlorophyll during photosynthesis.
- **B** Spinach leaves contain several pigments.
- **C** Spinach leaves contain more orange pigment than yellow pigment.
- **D** Spinach leaves are yellow-orange rather than green.

10. In which organelle would MOST of these pigments be found?
- **A** vacuoles
- **B** centrioles
- **C** mitochondria
- **D** chloroplasts

Open-Ended Response

11. Describe how high-energy electrons are ultimately responsible for driving the reactions of photosynthesis.

If You Have Trouble With . . .											
Question	1	2	3	4	5	6	7	8	9	10	11
See Lesson	8.1	8.2	8.2	8.2	8.2	8.3	8.3	8.2	8.2	8.2	8.3

9 Cellular Respiration and Fermentation

Big idea

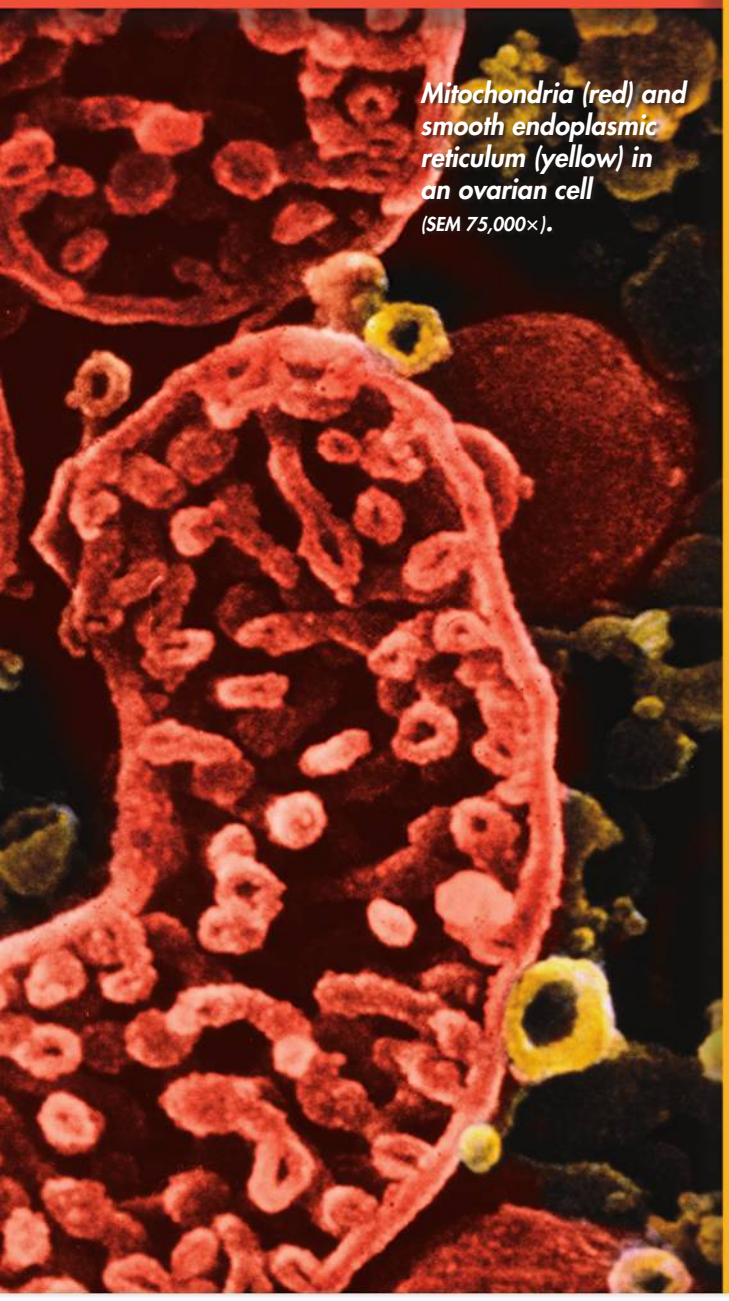
Cellular Basis of Life

Q: How do organisms obtain energy?

BIOLOGY.com Search Chapter 9 GO • Flash Cards

CHAPTER MYSTERY

INSIDE:



Mitochondria (red) and smooth endoplasmic reticulum (yellow) in an ovarian cell (SEM 75,000×).

- Untamed Science Video
- Chapter Mystery

DIVING WITHOUT A BREATH

You know what it is like to feel out of breath. Just a few minutes of hard exercise can have some people huffing and puffing for air. But what if you couldn't get air? What if you were asked to hold your breath and exercise? Before too long, you'd run out of oxygen and pass out. You would not be able to get enough oxygen. It may seem like a bad idea to hold your breath while exercising, but there are animals that do it all the time—whales. Because whales are air-breathing mammals, they still need to come to the surface for air. But after a breath, some whales can dive underwater for as long as 45 minutes! How is that possible? Diving takes a lot of energy. How do whales stay active for so long on only one breath?

Read for Mystery Clues As you read this chapter, look for clues to help you discover how whales can stay underwater so long. Then, solve the mystery at the end of the chapter.

FOUNDATIONS for Learning

Cells need chemical energy to stay alive. Special parts of the cell help them get this energy. Before you read the chapter, label six index cards with the words *water*, *pyruvic acid*, *carbon dioxide*, *oxygen*, *energy*, and *glucose*. Label one sheet of paper with the words *cytoplasm* and *mitochondrion*. At the end of the chapter are two activities that use the cards and sheet of paper. They will help you answer the question: How do organisms obtain energy?

9.1 Cellular Respiration: An Overview

Key Questions

- ***Where do organisms get energy?***
- ***What is cellular respiration?***
- ***What is the relationship between photosynthesis and cellular respiration?***

BUILD Understanding

Preview Visuals Before you read, study The Stages of Cellular Respiration figure. Make a list of questions that you have about the figure. As you read, write down the answers to the questions.

In Your Workbook Go to your workbook to learn more about Previewing Visuals. Complete the Previewing Visuals activity for Lesson 9.1.

Chemical Energy and Food

How do you feel when you are hungry? Do you feel sluggish, dizzy, or a little weak? That weakness comes from a lack of the food you need for energy. But what does food have to do with energy?

Food gives living things the energy they need to grow. Some living things, such as plants, are autotrophs (AW toh trohfs). They make their own food through photosynthesis. Other living things are heterotrophs (HET ur oh trohfs). They have to eat other living things for food. For all living things, food molecules store chemical energy. Living things release that energy when they break those food molecules down.

Energy in food can be measured in units called calories. A calorie is the amount of energy needed to raise the temperature of 1 gram of water 1 degree Celsius. The Calorie you see on food labels is actually a kilocalorie, or 1000 calories. The amount of energy in different kinds of food varies. This is because of differences in the way the atoms in food molecules are bonded together. For example, 1 gram of the sugar glucose gives off 3811 calories of energy when it is burned. But, 1 gram of the fat found in beef gives off 8893 calories of energy when it is burned.

Cells break down food molecules over time, getting a little bit of chemical energy at key steps. This chemical energy helps cells use the energy in foods to make compounds such as ATP. ATP and other useful energy compounds directly power the activities of the cell.

Key Question Where do organisms get energy?
Organisms get the energy they need from food.

A Controlled Release The energy stored in food is released slowly. If the energy were given off all at once, most of it would be lost as light and heat. That is what happens when a marshmallow catches fire.

INQUIRY into Scientific Thinking

You Are What You Eat

Different types of food can store very different amounts of energy. Most foods have a mix of proteins, carbohydrates, and fats. One gram of protein or a carbohydrate such as glucose has about 4 Calories. One gram of fat, though, has about 9 Calories. The table to the right shows what is found in one serving of some common foods.

Composition of Some Common Foods

Food	Protein (g)	Carbohydrate (g)	Fat (g)
Apple, 1 medium	0	22	0
Bacon, 2 slices	5	0	6
Chocolate, 1 bar	3	23	13
Eggs, 2 whole	12	0	9
2% milk, 1 cup	8	12	5
Potato chips, 15 chips	2	14	10
Skinless roasted turkey, 3 slices	11	3	1

1. Interpret Data The food from the table that has the most protein is _____. The food that has the most carbohydrates is _____. The food that has the most fat is _____.

2. Calculate

a. How many Calories total are there in 2 slices of bacon?

b. How many Calories total are there in 3 slices of roasted turkey?

c. What is the difference in total Calories between these two foods? Why is there a difference?

3. Calculate Walking uses around 5 Calories per minute. At that rate, how many minutes would you have to walk to burn the Calories in one chocolate bar? Use the equations below to help you with your calculations.

_____ Calories from protein
\+ _____ Calories from carbohydrates
\+ _____ Calories from fat
= _____ Total Calories in a chocolate bar

$$\frac{\text{\_\_\_\_ Total Calories}}{\text{5 Calories/minute}} = \text{\_\_\_\_ minutes}$$

In Your Workbook Get more help for this activity in your workbook.

Overview of Cellular Respiration

Living things can get energy from food through cellular respiration. **Cellular respiration** is the process that releases energy from food, such as the simple sugar glucose, when there is oxygen present. Cellular respiration gives off carbon dioxide, water, and energy. The process can be summarized like this:

$$6O_2 + C_6H_{12}O_6 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

But cellular respiration does not take place in just one step. If it did, all of the energy from sugar would be given off at once. Most of it would be lost in the form of light and heat. A living cell has to release the chemical energy in food molecules a little bit at a time. The cell uses that energy to make ATP.

Key Question What is cellular respiration?

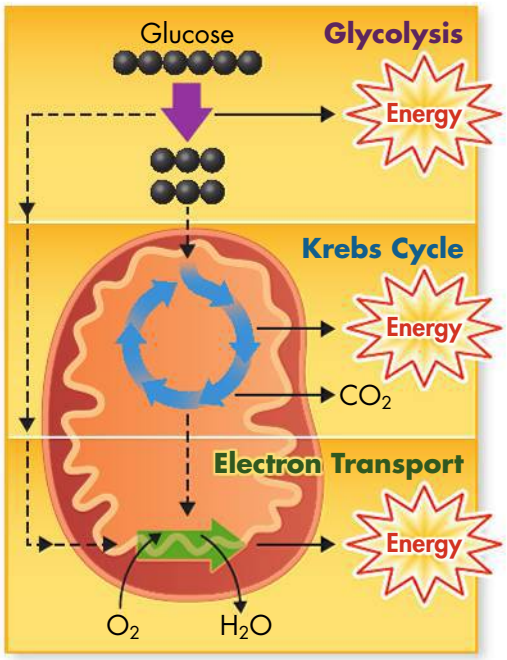
Cellular respiration is the process that releases energy from food when oxygen is present.

BUILD Vocabulary

cellular respiration
the process that releases energy by breaking down glucose and other food molecules in the presence of oxygen

MULTIPLE MEANINGS

Respiration is another word for breathing, the exchange of oxygen and carbon dioxide within the lungs. Cellular respiration requires the same exchange of gases, only within the living cell.



The Stages of Cellular Respiration There are three stages to cellular respiration: glycolysis, the Krebs cycle, and the electron transport chain.

Three Main Stages Cellular respiration gets energy from food in three stages. These stages are glycolysis, the Krebs cycle, and the electron transport chain. When looking at these stages, it is helpful to use an example. We will use the sugar glucose. Glucose enters the first stage, known as glycolysis (gly KAHL ih sis). Only a small amount of energy is used to make ATP during this stage. The rest is still locked in the bonds of a molecule called pyruvic (py ROO vik) acid. Pyruvic acid enters the second stage, the Krebs cycle, where a little more energy is given off. Most of the energy from cellular respiration comes from the last stage, the electron transport chain. This stage uses oxygen and reactants from the other two stages to finish the job.

Oxygen and Energy You get oxygen from the air you breathe. Oxygen is used at the end of the electron transport chain. Any time a cell needs more energy, it needs more oxygen, too. That is why you breathe hard when you exercise. You use up energy and need more oxygen, which means taking more breaths.

Chemical pathways that need oxygen are called **aerobic,** which means "in air." The Krebs cycle and electron transport chain are both aerobic. Even though the Krebs cycle does not directly need oxygen, it cannot run without the electron transport chain, which does need oxygen. Glycolysis, however, does not need oxygen. It does not depend on an aerobic process, either. Glycolysis is **anaerobic,** which means "without air."

Mitochondria (myt oh KAHN dree uh) are the organelles most important in cellular respiration. Glycolysis actually takes place in the cytoplasm of a cell, but the Krebs cycle and electron transport chain take place inside the mitochondria. If oxygen is not present, another anaerobic path, known as fermentation, keeps glycolysis running. You will learn more about fermentation later in this chapter.

BUILD Vocabulary

aerobic
a process that requires oxygen

anaerobic
a process that does not require oxygen

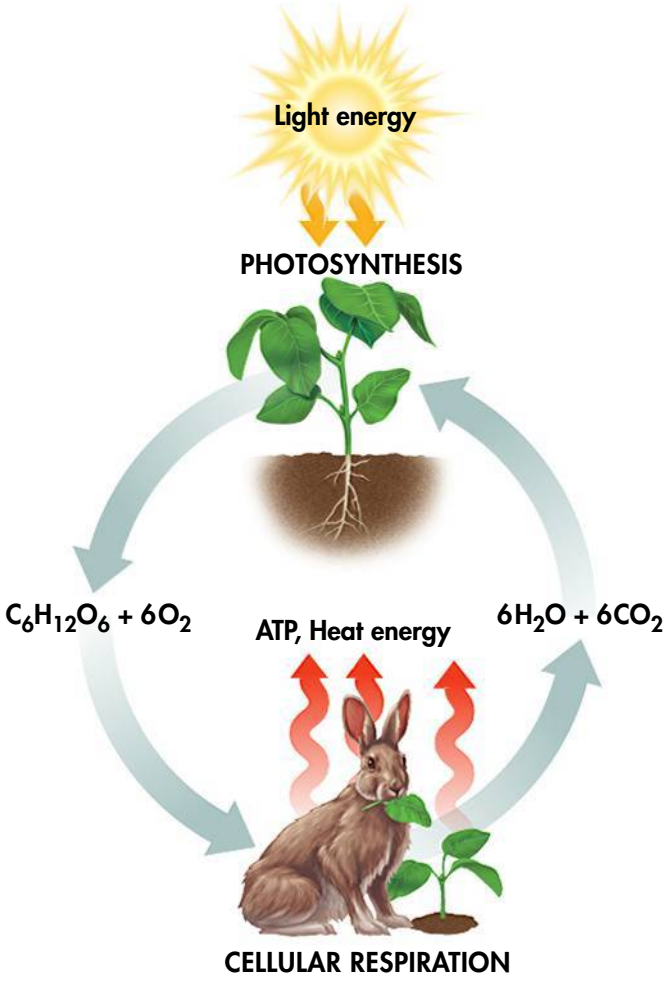
PREFIXES

The prefix *an-* means "without" and the prefix *aero-* means "air." *Aerobic* means "with air" and *anaerobic* means "without air."

Comparing Photosynthesis and Cellular Respiration

If nearly all living things break down food through cellular respiration, why doesn't Earth run out of oxygen? Where does all of the carbon dioxide go? Where do the cells get food molecules from? Cellular respiration is balanced by photosynthesis. The energy from each process flows in opposite directions. The equations for photosynthesis and cellular respiration are the reverse of each other. Photosynthesis removes carbon dioxide from the air. Cellular respiration puts it back. Photosynthesis gives off oxygen and makes sugars. Cellular respiration uses that oxygen to get energy from sugars. Cellular respiration takes place in nearly all life: plants, animals, fungi, protists, and most bacteria. Photosynthesis, on the other hand, takes place only in plants, algae, and some bacteria.

Key Question What is the relationship between photosynthesis and cellular respiration?
Photosynthesis produces food molecules and removes carbon dioxide from the air, and cellular respiration puts it back. Photosynthesis gives off oxygen, and cellular respiration uses that oxygen to release energy from food.



Opposite Processes Photosynthesis and cellular respiration can be thought of as opposite processes.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A process that needs oxygen to take place is called _____.
2. Glycolysis is _____ because it can happen when there is no oxygen.

Critical Thinking

3. **Infer** Do plant cells carry out cellular respiration? What organelle do they have that helps you know the answer?
4. **Compare and Contrast** How are the equations for cellular respiration and photosynthesis similar? How are they different?
5. **Apply Concepts** Aerobics is a kind of exercise that involves rhythmic movement and stretching, usually to music. What does the name *aerobics* tell you about this kind of exercise?
6. **Write to Learn** Answer the first clue of the mystery. Think about the difference between aerobic and anaerobic processes.

MYSTERY CLUE

If whales stay underwater for 45 minutes or more, do you think they mostly use aerobic or anaerobic processes? (Hint: See p. 214.)

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9.2 The Process of Cellular Respiration

Key Questions

- ***What happens during the process of glycolysis?***
- ***What happens during the Krebs cycle?***
- ***How does the electron transport chain use high-energy electrons from glycolysis and the Krebs cycle?***
- ***How much ATP does cellular respiration generate?***

BUILD Understanding

Compare/Contrast Table As you read, make a compare/contrast table for glycolysis, the Krebs cycle, and the electron transport chain. In your table, show where each step takes place, what reactants it uses, what products it makes, and how many molecules of ATP are made.

In Your Workbook Go to your workbook to learn more about making a compare/contrast table. Complete the compare/contrast table for Lesson 9.2.

Glycolysis

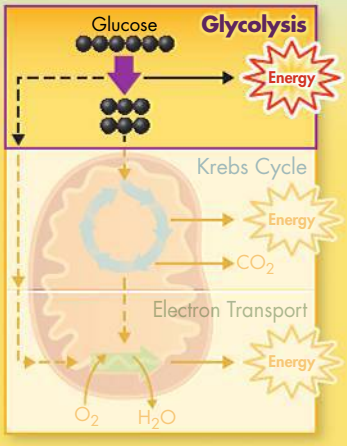
Food burns. In fact, flour is so flammable that is has caused many explosions. Because of this, you should never store flour above a stove. But how do living things get the energy they need from food without starting a fire?

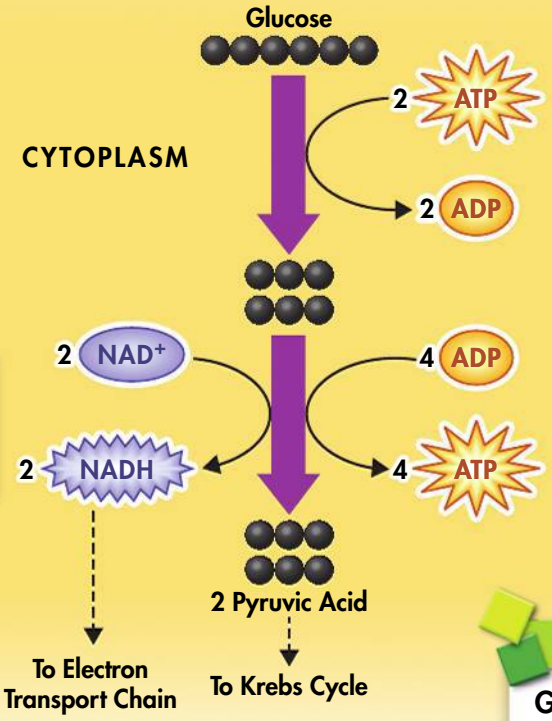
Living things use a series of reactions and steps to get energy from food molecules. The first set of reactions in cellular respiration is known as **glycolysis.** In one of the reactions of glycolysis, a 6-carbon sugar made from glucose is split into two. The final step produces two molecules of pyruvic acid. Pyruvic acid has 3 carbons. Energy is given off as the bonds in glucose are broken and formed again between different atoms.

Making ATP Glycolysis gives off energy. But the cell needs to put in a little energy to get things going. At the beginning, 2 ATP molecules are used up. Glycolysis makes 4 ATP molecules. This gives the cell a net gain of 2 ATP molecules for each molecule of glucose that enters glycolysis.

Making NADH One of the steps of glycolysis passes 4 electrons to an electron carrier. This carrier is called **NAD^+,** or nicotinamide adenine dinucleotide. Like $NADP^+$ in photosynthesis, each NAD^+ molecule can pick up a hydrogen ion and carry a pair of high-energy electrons. The new molecule is known as NADH. It holds the electrons until they can be moved to other molecules. Later on, when there is oxygen present, these high-energy electrons can be used to make even more ATP.

Breaking Down Sugars Animals get sugars from food. Sugars such as glucose are then broken down by cells through the process of glycolysis.





Splitting glucose to make 2 smaller molecules takes 2 molecules of ATP.

NAD^+ picks up 4 high-energy electrons from a glycolysis reaction. This step makes 2 NADH.

The last steps make 4 molecules of ATP, which means a net gain of 2 ATP.

BUILD Connections

Glycolysis Glycolysis is the first stage of cellular respiration. During glycolysis, glucose is broken down into 2 molecules of pyruvic acid. ATP and NADH are also made.

Why Glycolysis Is Useful During glycolysis, 4 ATP molecules are made from 4 ADP molecules. Given that 2 ATP molecules are used to start the process, there is a net gain of just 2 ATP molecules. Even though the energy given off by glycolysis is small, the process is so fast that cells can make thousands of ATP molecules in just a few milliseconds. The speed of glycolysis can be a big plus when the cell suddenly needs a lot of energy.

Besides speed, another useful thing about glycolysis is that it does not need oxygen. This means that glycolysis can quickly get chemical energy to cells when there is not any oxygen present. When oxygen is present, however, the pyruvic acid and NADH made during glycolysis become the materials needed for the other stages of cellular respiration.

Key Question What happens during the process of glycolysis?
During glycolysis, 1 molecule of glucose, which has 6 carbon atoms, is changed into 2 molecules of pyruvic acid, which each have 3 carbon atoms.

BUILD Vocabulary

glycolysis
The first set of reactions in cellular respiration in which a molecule of glucose is broken into two molecules of pyruvic acid

NAD^+
nicotinamide adenine dinucleotide: an electron carrier involved in glycolysis

WORD ORIGINS

The Greek word *glukus* means "sweet." The Latin word *lysis* means to "loosen." The term *glycolysis* thus means "loosening" or "breaking glucose."

BUILD Vocabulary

Krebs cycle
The second stage of cellular respiration in which pyruvic acid is broken down into carbon dioxide in a series of energy-extracting reactions.

matrix
the innermost compartment of the mitochondrion

WORD ORIGINS

The Krebs cycle was named after the British biologist Hans Krebs, who won the Nobel Prize in 1953 for its discovery.

The Krebs Cycle

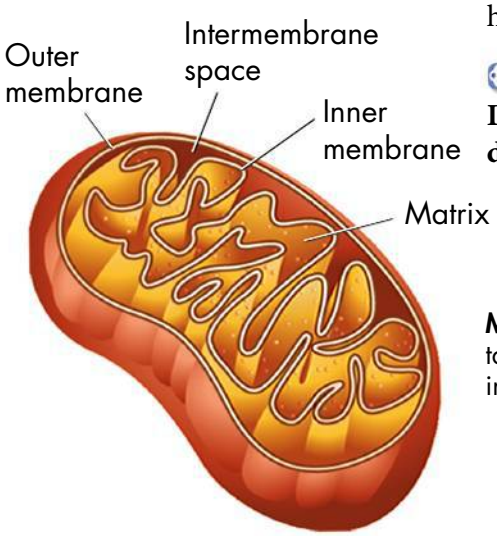
When there is oxygen present, pyruvic acid made in glycolysis passes to the second stage of cellular respiration. This stage is called the **Krebs cycle.** During the Krebs cycle, pyruvic acid is broken down over many steps.

Making Citric Acid The Krebs cycle begins when pyruvic acid goes into the mitochondrion. It passes two membranes and goes into the matrix. The **matrix** is the innermost part of the mitochondrion. The Krebs cycle takes place here. Once inside the matrix, 1 carbon is split off from pyruvic acid, releasing a molecule of carbon dioxide. The other 2 carbon atoms join a 4-carbon molecule already present in the cycle. They form citric acid, which has 6 carbons. As the cycle keeps going, citric acid is broken down. More carbon dioxide is given off, and high-energy electrons are moved to energy carriers, such as NAD^+. As each molecule of carbon dioxide leaves, the citric acid molecule loses a carbon atom. In the end a 4-carbon molecule is formed. Then the cycle begins all over again.

Electron Carriers as Energy For each turn of the cycle, a phosphate is added to ADP to make ATP. Each glucose molecule causes two complete turns of the Krebs cycle. So, for each molecule of glucose, the cycle makes two more ATP molecules. When we add these to the two made in glycolysis, so far we have gained just 4 ATP molecules. That doesn't sound like much. However, most of the chemical energy released in the cycle goes to produce high-energy electrons. These are passed to the electron carriers NAD^+ and FAD. This changes them into NADH and $FADH_2$.

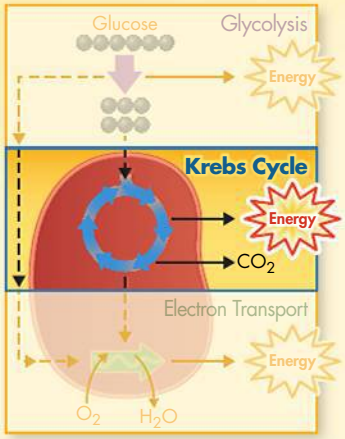
What happens to the carbon dioxide, ATP, and electron carriers produced in the Krebs cycle? Carbon dioxide is not useful to the cell. It is expelled every time you breathe out. The ATP molecules are very useful. They are immediately available as energy for cellular activities. When oxygen is present, the electron carrier molecules are used make huge amounts of ATP.

Key Question What happens during the Krebs cycle?
During the Krebs cycle, pyruvic acid is broken down into carbon dioxide in a series of steps that releases chemical energy.



Mitochondrion

Mitochondrion The Krebs cycle takes place within the matrix, or the innermost space, of the mitochondrion.



BUILD Connections

The Krebs Cycle During the Krebs cycle, pyruvic acid from glycolysis is used to make carbon dioxide, NADH, ATP, and $FADH_2$. Because glycolysis makes 2 molecules of pyruvic acid from each glucose molecule, the Krebs cycle "turns" twice for each glucose molecule that enters glycolysis.

CYTOPLASM

Outer mitochondrial membrane

Pyruvic Acid

1 Pyruvic acid from glycolysis enters the mitochondrion's matrix.

Inner mitochondrial membrane

2 Enzymes split CO_2 off from pyruvic acid, leaving a 2-carbon molecule. NADH is produced from NAD^+.

MATRIX

NAD^+

NADH

CO_2

6 The 4-carbon-atom molecule can go through the cycle again.

3 The 2-carbon-atom molecule joins a 4-carbon-atom molecule to become citric acid.

Citric Acid

NADH

NAD^+

5 More reactions make high-energy molecules of ATP, $FADH_2$, and NADH .

CO_2

NAD^+

NADH

CO_2

$FADH_2$

FAD

NAD^+

NADH

ATP

ADP

4 More CO_2 and NADH are made as citric acid becomes a 4-carbon-atom molecule.

To Electron Transport Chain

To Electron Transport Chain

Electron Transport and ATP Synthesis

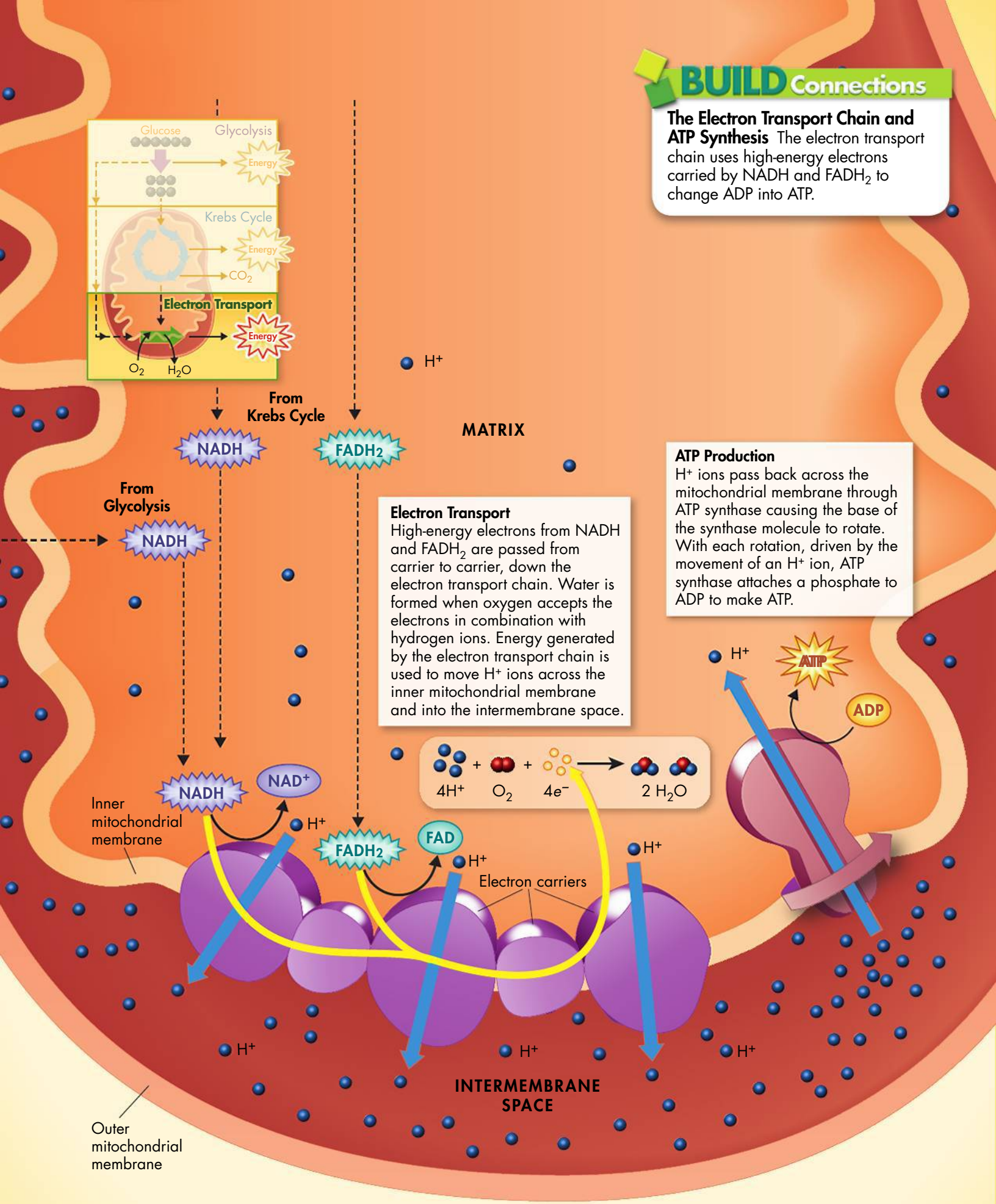
Carriers from glycolysis and the Krebs cycle go into the last stage of cellular respiration. This last stage is the electron transport chain. The NADH made during glycolysis can enter the mitochondrion. There, they join the NADH and $FADH_2$ made by the Krebs cycle. Electrons are then passed from all of those carriers to the electron transport chain. The electron transport chain uses them to change ADP into ATP.

Electron Transport High-energy electrons are passed from one carrier to the next. At the end of the electron transport chain, an enzyme adds these electrons to hydrogen ions and oxygen to form water. Every time 2 electrons pass down the chain, their energy is used to move hydrogen ions (H^+) across the inner mitochondrial membrane. As this happens, H^+ ions build up in the intermembrane space. That space becomes more positively charged than the matrix.

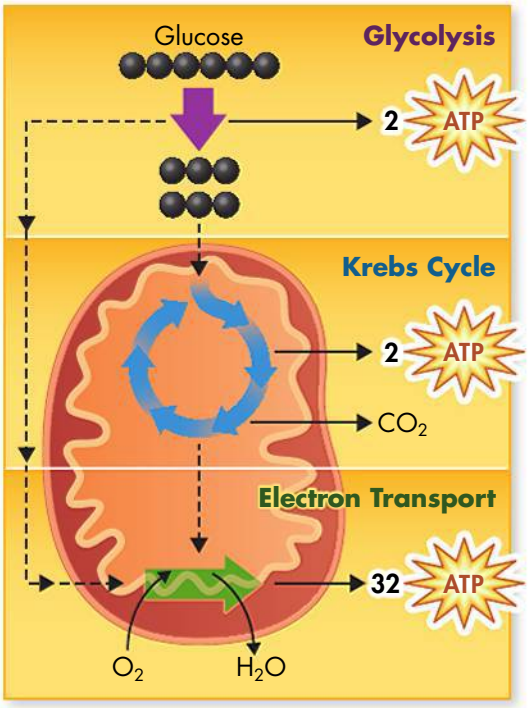
Making ATP The cell uses this charge difference between the two spaces to make ATP. As in photosynthesis, the cell uses enzymes known as ATP synthases. The charge difference makes the H^+ ions move through channels in these enzymes. Each time a H^+ ion moves through it, the ATP synthase turns. With each turn, the enzyme attaches a phosphate to ADP to produce ATP. On average, each pair of high-energy electrons that moves down the full length of the electron transport chain gives off enough energy to make 3 molecules of ATP.

Key Question How does the electron transport chain use high-energy electrons from glycolysis and the Krebs cycle?
The electron transport chain uses the high-energy electrons from glycolysis and the Krebs cycle to change ADP into ATP.

Electron Transport The electron transport chain provides most of the energy that athletes use during cellular respiration.


BUILD Connections
The Electron Transport Chain and ATP Synthesis The electron transport chain uses high-energy electrons carried by NADH and $FADH_2$ to change ADP into ATP.
Glucose
Glycolysis
Energy
Krebs Cycle
Energy
CO_2
Electron Transport
Energy
O_2
H_2O
H^+
From Krebs Cycle
NADH
$FADH_2$
MATRIX
From Glycolysis
NADH
Electron Transport
High-energy electrons from NADH and $FADH_2$ are passed from carrier to carrier, down the electron transport chain. Water is formed when oxygen accepts the electrons in combination with hydrogen ions. Energy generated by the electron transport chain is used to move H^+ ions across the inner mitochondrial membrane and into the intermembrane space.
ATP Production
H^+ ions pass back across the mitochondrial membrane through ATP synthase causing the base of the synthase molecule to rotate. With each rotation, driven by the movement of an H^+ ion, ATP synthase attaches a phosphate to ADP to make ATP.
H^+
ATP
ADP
$4H^+$ + O_2 + $4e^-$ → $2\ H_2O$
NADH
NAD^+
Inner mitochondrial membrane
H^+
$FADH_2$
FAD
H^+
Electron carriers
H^+
H^+
H^+
H^+
INTERMEMBRANE SPACE
Outer mitochondrial membrane
CYTOPLASM

Energy Totals Breaking down glucose through cellular respiration makes 36 molecules of ATP.



The Totals

Together, glycolysis, the Krebs cycle, and the electron transport chain make about 36 molecules of ATP per molecule of glucose. We eat more than just glucose, of course, but that's no problem for the cell. Complex sugars are broken down to simple sugars such as glucose. Lipids and proteins can be broken down into molecules that enter the Krebs cycle or glycolysis. Like a furnace, a cell can use more than one type of reactant, not just glucose, to produce energy. Both the cell and the furnace release heat.

How good is cellular respiration at capturing chemical energy? Those 36 ATP molecules represent about 36 percent of the total energy of glucose. That might not seem like much, but it means that the cell is actually better at using food than a car's engine is at burning gasoline! Just as the fuel in a car, the rest of the energy of glucose is given off as heat. This extra heat is one of the reasons your body feels warmer after exercise, and why your body temperature stays the same day and night.

Key Question How much ATP does cellular respiration generate?

Together, glycolysis, the Krebs cycle, and the electron transport chain make about 36 molecules of ATP per molecule of glucose.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. Glucose is first split during _____.
2. _____ is an electron carrier that is used during glycolysis and the Krebs cycle.
3. During the _____, pyruvic acid is broken down into carbon dioxide.
4. The Krebs cycle takes place in the _____.

Critical Thinking

5. **Compare and Contrast** How is the function of NAD^+ similar to that of $NADP^+$?
6. **Infer** Why do you often breathe faster during heavy exercise? How is this related to oxygen and cellular respiration?
7. **Use Analogies** How is the cell like a furnace?
8. **Write to Learn** Answer the second clue of the mystery. In your answer, describe how whales and humans differ in their ability to stand CO_2 buildup in blood.

MYSTERY CLUE

When we are underwater, our bodies react to a buildup of CO_2 in the blood. This buildup makes us want to go to the surface and gasp for breath. The average human can hold his or her breath for only about a minute. Whales stay underwater for much longer. What does this suggest about a whale's ability to stand CO_2? (Hint: See p. 218.)

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9.3 Fermentation

Fermentation

How do your cells get energy when you use up oxygen so quickly that you cannot get more oxygen fast enough? And what about organisms that live in places where there isn't oxygen? How do their cells get energy from food?

Glycolysis can make ATP quickly and it does not need oxygen. However, in just a few seconds, glycolysis fills all of the cell's NAD^+ molecules with electrons. Without oxygen, the electron transport chain does not run, so there is nowhere for the NADH molecules to leave their electrons. So, NADH doesn't get converted back to NAD^+. Without NAD^+, the cell cannot keep glycolysis going. That's where fermentation comes in. When oxygen is not present, glycolysis is followed by **fermentation.** During fermentation, cells change NADH to NAD^+ by passing the electrons back to pyruvic acid. The NAD^+ can then fuel glycolysis again. The cells can make ATP again. Fermentation is an aerobic process and takes place in the cytoplasm. Sometimes glycolysis and fermentation are called anaerobic respiration. There are two different kinds—alcoholic fermentation and lactic acid fermentation.

Alcoholic Fermentation Yeasts and a few other microorganisms use alcoholic fermentation. A summary of alcoholic fermentation after glycolysis is as follows:

$$\text{Pyruvic acid} + \text{NADH} \longrightarrow \text{Alcohol} + CO_2 + NAD^+$$

Humans use alcoholic fermentation to make alcoholic beverages. It is also what causes bread dough to rise. When yeast cells in the dough run out of oxygen, the dough begins to give off tiny bubbles of carbon dioxide. These bubbles form the air spaces you see in a slice of bread. The small amount of alcohol made in the dough evaporates when the bread is baked.

Key Questions

- ***How do organisms generate energy when oxygen is not available?***
- ***How does the body produce ATP during different stages of exercise?***

BUILD Understanding

Venn Diagram As you read, create a Venn diagram that compares alcoholic fermentation and lactic acid fermentation.

In Your Workbook Go to your workbook to learn more about making a Venn diagram. Complete the Venn diagram for Lesson 9.3.

BUILD Vocabulary

fermentation
the process by which cells release energy in the absence of oxygen

RELATED WORD FORMS

The noun *fermentation* and the verb *ferment* are related word forms. Dough that is beginning to ferment is just starting to undergo the process of fermentation.

Lactic Acid Fermentation Most living things carry out fermentation by changing pyruvic acid into lactic acid. Unlike alcoholic fermentation, lactic acid fermentation does not give off carbon dioxide. Like alcoholic fermentation, lactic acid fermentation makes NAD^+ so that glycolysis can continue. Lactic acid fermentation after glycolysis can be written as:

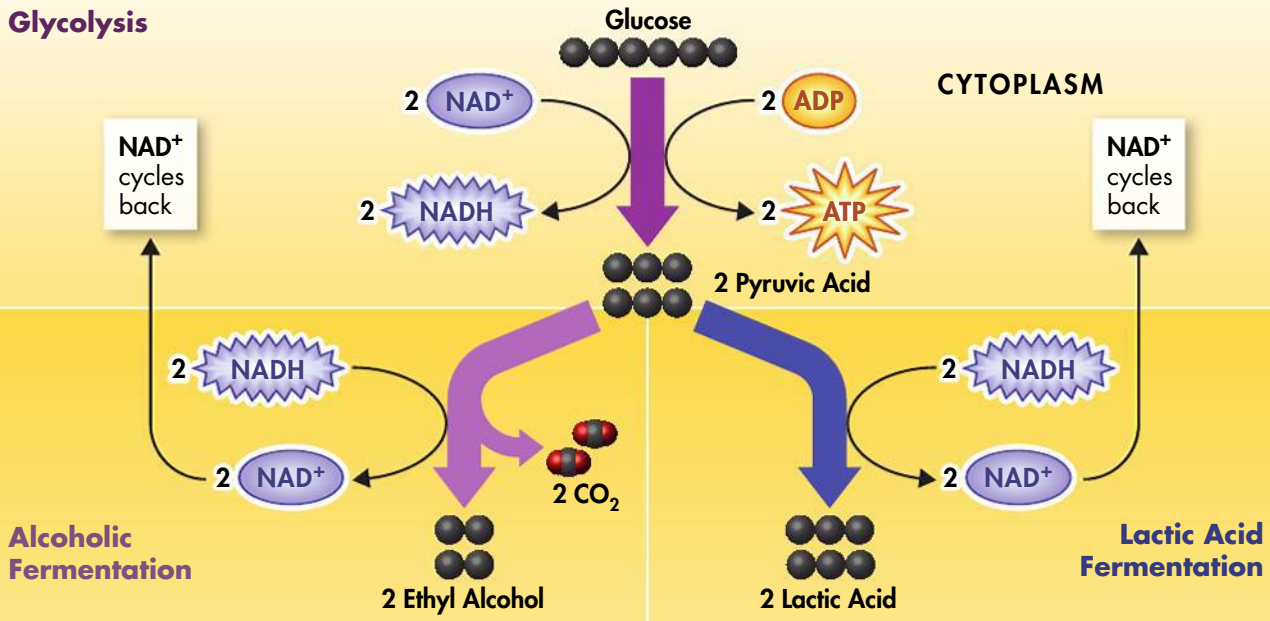
$$\text{Pyruvic acid} + \text{NADH} \longrightarrow \text{Lactic acid} + NAD^+$$

Bacteria that use lactic acid fermentation are used to make many kinds of foods. Examples are cheese, yogurt, buttermilk, and sour cream. The acid is part of why these foods have a sour taste. Many kinds of pickles, sauerkraut, and kimchi are also made using lactic acid fermentation.

People also use lactic acid fermentation. Many of the cells in our body are able to make ATP by lactic acid fermentation when they are without oxygen for a few seconds. Muscle cells use this kind of fermentation when they need a lot of ATP for quick bursts of activity.

Lactic acid builds up in muscles after a burst of activity. The only way to get rid of lactic acid is in a chemical pathway that uses extra oxygen. This is why exercise can leave you huffing and puffing.

Key Question How do organisms generate energy when oxygen is not available?
In the absence of oxygen, fermentation releases energy from food molecules by making ATP.



Fermentation In alcoholic fermentation, pyruvic acid from glycolysis is changed into alcohol and carbon dioxide. In lactic acid fermentation, pyruvic acid from glycolysis is changed into lactic acid.

Energy and Exercise

Think about the last time you ran a race. At each stage of the race your body used different paths to get energy. You have three main sources of ATP: ATP already in muscles, ATP made by lactic acid fermentation, and ATP made by cellular respiration. At the beginning of a race, the body uses all three sources. However, stored ATP and lactic acid fermentation can give energy only for a short time.

Quick Energy Cells usually have only a little ATP stored up from cellular respiration. At the very beginning of a race, the muscles have only enough for a few seconds of activity. Usually by the 50-meter mark, that store of ATP is nearly gone. Then, the muscle cells make their ATP by lactic acid fermentation, which gives enough ATP to last about 90 seconds, or about 200 or 300 meters.

Long-Term Energy For exercise longer than about 90 seconds, cellular respiration is the only way to keep making ATP. Your body stores energy in muscle in the form of the carbohydrate glycogen. These stores are usually enough to last for 15 or 20 minutes of activity. After that, your body begins to break down other stored molecules, including fats, for energy.

Key Question How does the body produce ATP during different stages of exercise?
For quick bursts of energy, the body uses ATP already in muscles and ATP from lactic acid fermentation. For exercise longer than 90 seconds, the body uses cellular respiration.

Energy and Exercise During a race, runners rely on the energy supplied by ATP to make it to the finish line.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete the following sentence correctly.

1. When there is no oxygen present, the cell uses _____ to make ATP.

Critical Thinking

2. Compare and Contrast What reactants and products do the two types of fermentation have in common?

3. Apply Why do runners breathe heavily after a sprint race?

4. Sequence List the body's sources of energy in the order in which they are used during a long-distance race.

5. Infer Why might aerobic exercise help someone lose weight?

6. Write to Learn Answer the third clue of the mystery. In your answer explain what whales do with lactic acid from fermentation.

MYSTERY CLUE

Whales use lactic acid fermentation to get much of their energy during a deep dive. If they can't breathe in to get oxygen, what do they do with all of the lactic acid made by fermentation? (Hint: See p. 224.)

BIOLOGY.com Search Lesson 9.3 GO • Lesson Assessment

Pre-Lab: Comparing Fermentation Rates of Sugars

Problem How does the type of sugar affect the rate of fermentation?

Materials computer, probe interface, gas pressure probe, hot plate, 400-mL beaker, thermometer, ring stand, test-tube clamp, medium test tube, test-tube rack, sugar solution, yeast suspension, pipettes, vegetable oil, 1-hole rubber stopper, plastic tubing with lock fitting

Lab Manual Chapter 9 Lab

Skills Focus Predict, Measure, Analyze Data, Infer

Connect to the Big idea In most cells, the pathways that release energy from food start with the conversion of glucose to pyruvic acid. This process does not require oxygen. When oxygen is present, however, pyruvic acid can react to form acetyl-CoA, which is used in the second stage of cellular respiration. When oxygen is not present, the pyruvic acid can be used in an anaerobic pathway. This alternate pathway from glucose to ATP is called fermentation. In this lab, you will use yeast to ferment sugars and compare the rates of fermentation.

Background Questions

a. **Review** What is the importance of the NAD^+ that is produced during the fermentation of pyruvic acid?

b. **Review** What other products are produced besides NAD^+ when yeast ferment sugar?

c. **Compare and Contrast** How are simple sugars different from disaccharides? (If needed, review Lesson 2.3 in your textbook.)

d. **Use Analogies** What do fermentation and a detour that drivers must use when roads are closed have in common?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Infer** Why do you think you will add a layer of vegetable oil above the sugar and yeast mixture?

2. **Relate Cause and Effect** Explain why it is possible to compare the rates of fermentation by measuring gas pressure in the test tubes.

3. **Predict** Which of the sugars do you think will have the highest rate of fermentation, and why?

BIOLOGY.com Search Chapter 9 GO

Visit Chapter 9 online to test yourself on chapter content as well as find activities to help you learn.

Untamed Science Video Go underwater with the Untamed Science crew to discover why marine mammals can stay submerged for such a long time.

Tutor Tube Improve your understanding of respiration by working "backward" from a breath of oxygen.

Art Review Review the components of electron transport and ATP synthesis.

InterActive Art See glycolysis and the Krebs cycle in action.

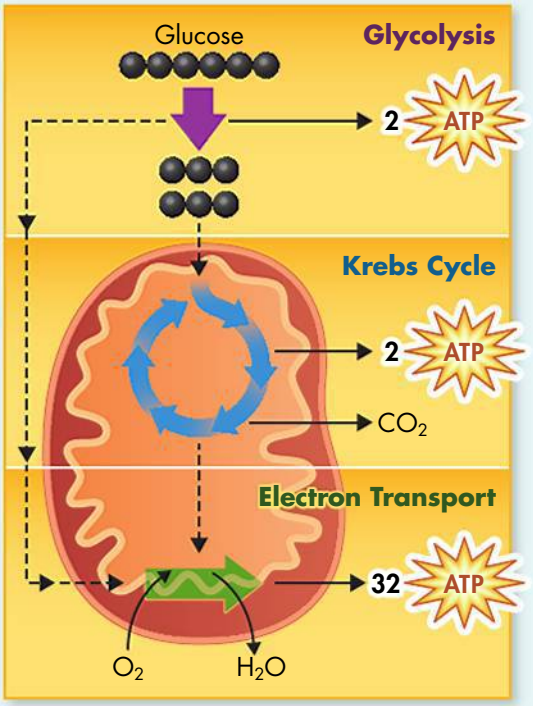
Art in Motion See how matter and energy cycle between photosynthesis and respiration.

9 CHAPTER Summary

9.1 Cellular Respiration: An Overview

- Living things get the energy they need from food.
- Cellular respiration is the process that releases energy from food when oxygen is present.
- Photosynthesis produces food molecules. Photosynthesis takes carbon dioxide from the air. Cellular respiration puts it back. Photosynthesis puts oxygen into the air. Cellular respiration uses that oxygen to get energy from food.

cellular respiration (p. 213)
aerobic (p. 214)
anaerobic (p. 214)



9.2 The Process of Cellular Respiration

- During glycolysis, 1 molecule of glucose, a 6-carbon compound, is changed into 2 molecules of pyruvic acid, a 3-carbon compound.
- During the Krebs cycle, pyruvic acid is broken down into carbon dioxide.
- The electron transport chain uses the high-energy electrons from glycolysis and the Krebs cycle to change ADP into ATP.
- Together, glycolysis, the Krebs cycle, and the electron transport chain make about 36 molecules of ATP per molecule of glucose.

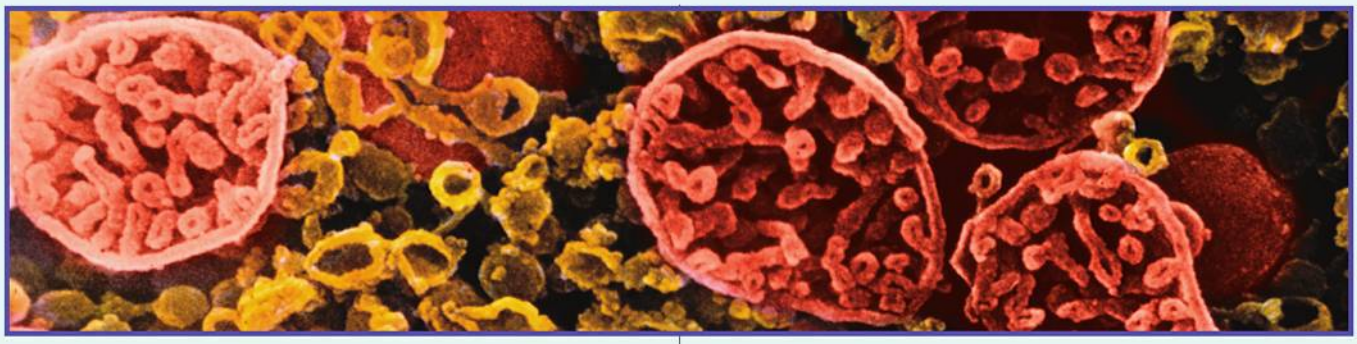
glycolysis (p. 216)
NAD^+ (p. 216)
Krebs cycle (p. 218)
matrix (p. 223)

9.3 Fermentation

- When there is no oxygen, fermentation releases energy from food molecules by making ATP.
- For short, quick bursts of energy, the body uses ATP already in muscles and ATP made by lactic acid fermentation.
- For exercise longer than about 90 seconds, cellular respiration is the only way to continue making ATP.

fermentation (p. 223)

9 CHECK Understanding



Assess the Big idea Cellular Basis of Life

Write an answer to the question below.
Q: How do organisms obtain energy?

Constructed Response

Write an answer to each of the questions below. The answer to each question should be one or two paragraphs. To help you begin, read the **Hints** below the questions.

1. **Carbon dioxide is a waste product of cellular respiration. Plants carry out both photosynthesis and cellular respiration. Why is it wrong to say that carbon dioxide is a waste product in plants?**

   Hint Photosynthesis and cellular respiration are opposite processes.

   Hint The reactants for photosynthesis are carbon dioxide and water.

2. **When you run a race, you usually have a burst of energy at the beginning. But, that burst of energy soon fades, and you eventually settle down to a steady pace. How do the different pathways that the body takes to get energy explain how different parts of a race feel?**

   Hint Muscle cells get energy from three different sources during a race.

   Hint Stored ATP and lactic acid fermentation can give energy only for a short time.

3. **Some kinds of bread are lighter and more airy than others. How might rising and baking temperature affect how dense bread is?**

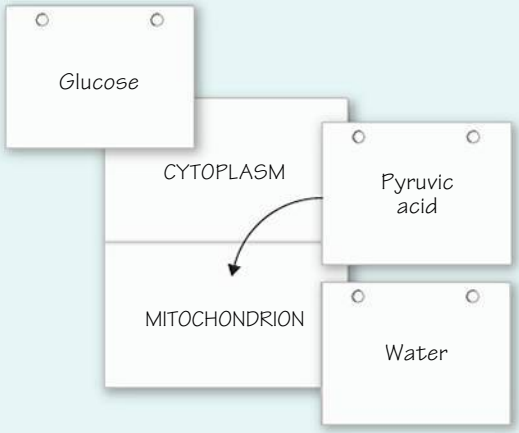
   Hint Enzymes in cellular process often work faster at higher temperatures.

   Hint The air bubbles in bread are caused by fermentation.

Foundations for Learning Wrap-Up

Use the index cards and notebook pages you prepared when you started the chapter as a tool to help you organize your thoughts about cellular respiration.

Activity 1 Working with a partner, use the index cards and notebook page to create a diagram to show the three stages of cellular respiration.



Activity 2 Working with a partner, label six more index cards with the chemical symbols for each word on the index cards from Activity 1. Then label three more index cards with +, +, and →. Now use the index cards to create a chemical equation that summarizes cellular respiration.

9.1 Cellular Respiration: An Overview

Understand Key Concepts

1. Cells use the energy stored in food to make
   a. ADP. **c.** glucose.
   b. ATP. **d.** water.

2. The process that gets energy from food when oxygen is present is
   a. ATP synthase. **c.** photosynthesis.
   b. cellular respiration. **d.** synthesis.

3. The first step in getting energy in the cell by breaking down glucose is known as
   a. the Krebs cycle. **c.** fermentation.
   b. electron transport. **d.** glycolysis.

Test-Taking Tip

Watch For Key Words Read questions carefully for key words such as *first, most,* or *last*. Question 3 asks for the "*first* step in getting energy in the cell by breaking down glucose." Answers **a**, **b**, and **c** are all steps in getting energy. But, **d** is the first step. So **d** glycolysis, is the correct answer.

4. What does it mean if a process is *anaerobic?* Which part of cellular respiration is anaerobic?

Think Critically

5. **Compare and Contrast** Why are cellular respiration and photosynthesis considered opposite reactions?

9.2 The Process of Cellular Respiration

Understand Key Concepts

6. The net gain of energy from glycolysis is
   a. 8 ADP molecules.
   b. 4 ATP molecules.
   c. 3 pyruvic acid molecules.
   d. 2 ATP molecules.

7. The Krebs cycle takes place within the
   a. chloroplast. **c.** mitochondrion.
   b. cytoplasm. **d.** nucleus.

8. The electron transport chain uses the high-energy electrons from the Krebs cycle to
   a. make glucose.
   b. convert glucose to pyruvic acid.
   c. convert pyruvic acid to citric acid.
   d. move H^+ ions across the inner mitochondrial membrane.

9. What powers the making of ATP by ATP synthase?
   a. the splitting of glycogen
   b. the spinning of the mitochondrion
   c. the movement of ions across the membrane
   d. the movement of electrons through membrane channels

10. What happens to high-energy electrons made during the Krebs cycle?

Think Critically

11. **Compare and Contrast** How is the function of NAD^+ in cellular respiration similar to that of $NADP^+$ in photosynthesis?

12. **Use Models** Draw and label a mitochondrion surrounded by cytoplasm. Show where glycolysis, the Krebs cycle, and the electron transport chain take place in a eukaryotic cell.

9.3 Fermentation

Understand Key Concepts

13. Because fermentation takes place without oxygen, it is said to be
   a. aerobic. **c.** cyclic.
   b. anaerobic. **d.** oxygen-rich.

9 CHECK Understanding

14. The process carried out by yeast that causes bread dough to rise is
    a. alcoholic fermentation.
    b. cellular respiration.
    c. lactic acid fermentation.
    d. mitosis.

15. Which of the following is a product of alcoholic fermentation?
    a. carbon dioxide **c.** oxygen
    b. lactic acid **d.** pyruvic acid

Think Critically

16. **Predict** Often, regular exercise causes the number of mitochondria in muscle cells to go up. How might that situation help someone do better at activities that use up a lot of energy?

Connecting the Concepts

Use Science Graphics

Use the nutritional information to answer questions 17 and 18.

Nutrition Facts

Serving Size	1 cup
Servings Per Container	About 2
Amount Per Serving	
Calories 250	Calories from Fat 108
	% Daily Value*
Total Fat 12g	18%
Saturated Fat 3g	15%
Trans Fat 3g	
Total Carbohydrate 31g	10%
Dietary Fiber 0g	0%
Sugars 5g	
Protein "?"	

17. **Apply Concepts** On average, how many Calories are there in 1 gram of a lipid, carbohydrate, and protein? Why the differences?

18. **Calculate** One gram of protein or a carbohydrate contains about 4 Calories. How many grams of protein must there be in this food in order to account for the number of Calories per serving shown in the label?

solve the CHAPTER MYSTERY

DIVING WITHOUT A BREATH

To be able to stay underwater for 45-minutes at a time, whales use many different tricks. For example, whale blood can handle the large amount of CO_2 that is made during the Krebs cycle. This lets whales stay underwater for a long time without making them feel a need to go to the surface. The Krebs cycle and electron transport need oxygen. And once the oxygen is used—and it's used quickly!—whale muscles use lactic acid fermentation to get energy. In humans, lactic acid causes the pH of the blood to drop. If the blood gets too acidic, a dangerous state called acidosis can take place. Whale muscles can handle a lot of lactic acid. The lactic acid stays in the muscles without causing acidosis. When whales come up after a long dive, they breathe in oxygen, which clears away the lactic acid buildup.

1. **Relate Cause and Effect** Why must whales have blood that can hold a lot of CO_2?

2. **Predict** Myoglobin is a molecule that stores oxygen in muscles. Would you expect to find more or less myoglobin than average in the muscle cells of whales if you were to look at them under the microscope?

3. **Infer** How might being able to dive into very deep water be an advantage for whales?

UntamedScience **Never Stop Exploring Your World.** Finding the solution to the mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. What raw materials are needed for cellular respiration?
- **A** glucose and carbon dioxide
- **B** glucose and oxygen
- **C** carbon dioxide and oxygen
- **D** oxygen and lactic acid

2. During the Krebs cycle
- **A** hydrogen ions and oxygen form water.
- **B** the cell gives off a small amount of energy through fermentation.
- **C** each glucose molecule is broken down into 2 molecules of pyruvic acid.
- **D** pyruvic acid is broken down into carbon dioxide over many steps.

3. Which substance is needed to begin glycolysis?
- **A** ATP
- **B** NADP
- **C** pyruvic acid
- **D** carbon dioxide

4. In eukaryotic cells, MOST of cellular respiration takes place in the
- **A** nuclei.
- **B** cytoplasm.
- **C** mitochondria.
- **D** cell walls.

5. Which substance is broken down during glycolysis?
- **A** carbon
- **B** NAD^+
- **C** glucose
- **D** pyruvic acid

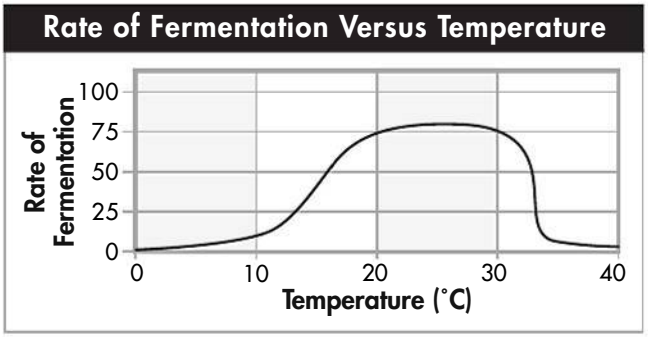
6. The human body can use all of the following as energy sources EXCEPT
- **A** ATP in muscles.
- **B** glycolysis.
- **C** lactic acid fermentation.
- **D** alcoholic fermentation.

7. During cellular respiration, which of the following are given off?
- **A** CO_2 and O_2
- **B** H_2O and O_2
- **C** O_2 and H_2O
- **D** CO_2 and H_2O

8. Which of the following is an aerobic process?
- **A** the Krebs cycle
- **B** glycolysis
- **C** alcoholic fermentation
- **D** lactic acid fermentation

Questions 9 and 10

The graph below shows the rate of alcoholic fermentation for yeast at different temperatures.



9. According to the graph, what is the relationship between the rate of fermentation and temperature?
- **A** The rate of fermentation continually increases as temperature increases.
- **B** The rate of fermentation continually decreases as temperature increases.
- **C** The rate of fermentation increases with temperature at first, then it rapidly decreases.
- **D** The rate of fermentation decreases with temperature at first, then it rapidly increases.

10. Which statement could explain the data shown in the graph?
- **A** The molecules that carry out fermentation perform best at temperatures above 30°C.
- **B** The yeast begins releasing carbon dioxide at 30°C.
- **C** The yeast cannot survive above 30°C.
- **D** The molecules that carry out fermentation perform best at temperatures below 10°C.

Open-Ended Response

11. Explain how a sprinter gets energy during a 30-second race. Is the process aerobic or anaerobic? Compare it to a long-distance runner getting energy during a 5-kilometer race.

If You Have Trouble With . . .

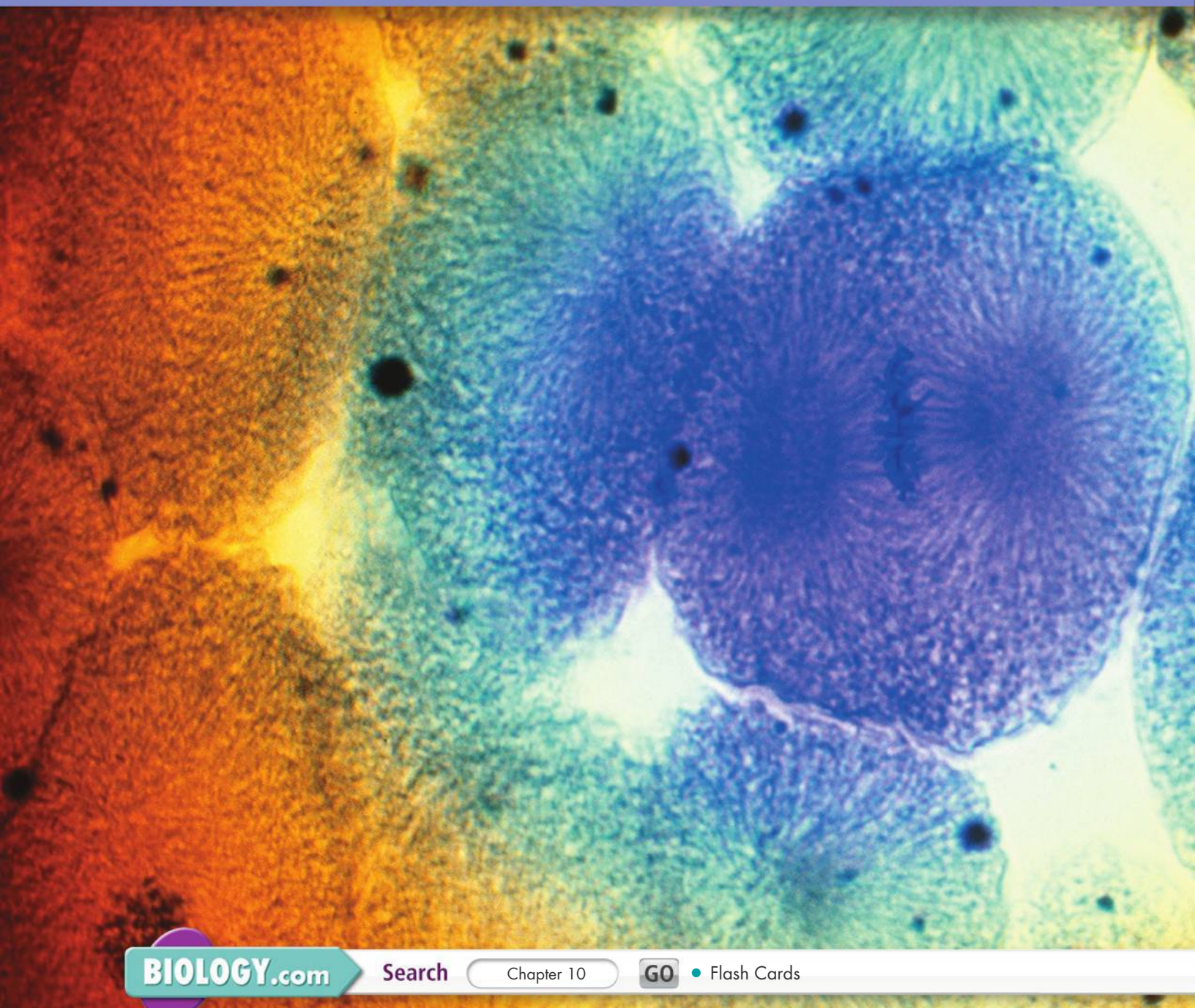
Question	1	2	3	4	5	6	7	8	9	10	11
See Lesson	9.1	9.2	9.2	9.1	9.2	9.3	9.1	9.1	9.3	9.3	9.3

10 Cell Growth and Division

Big idea

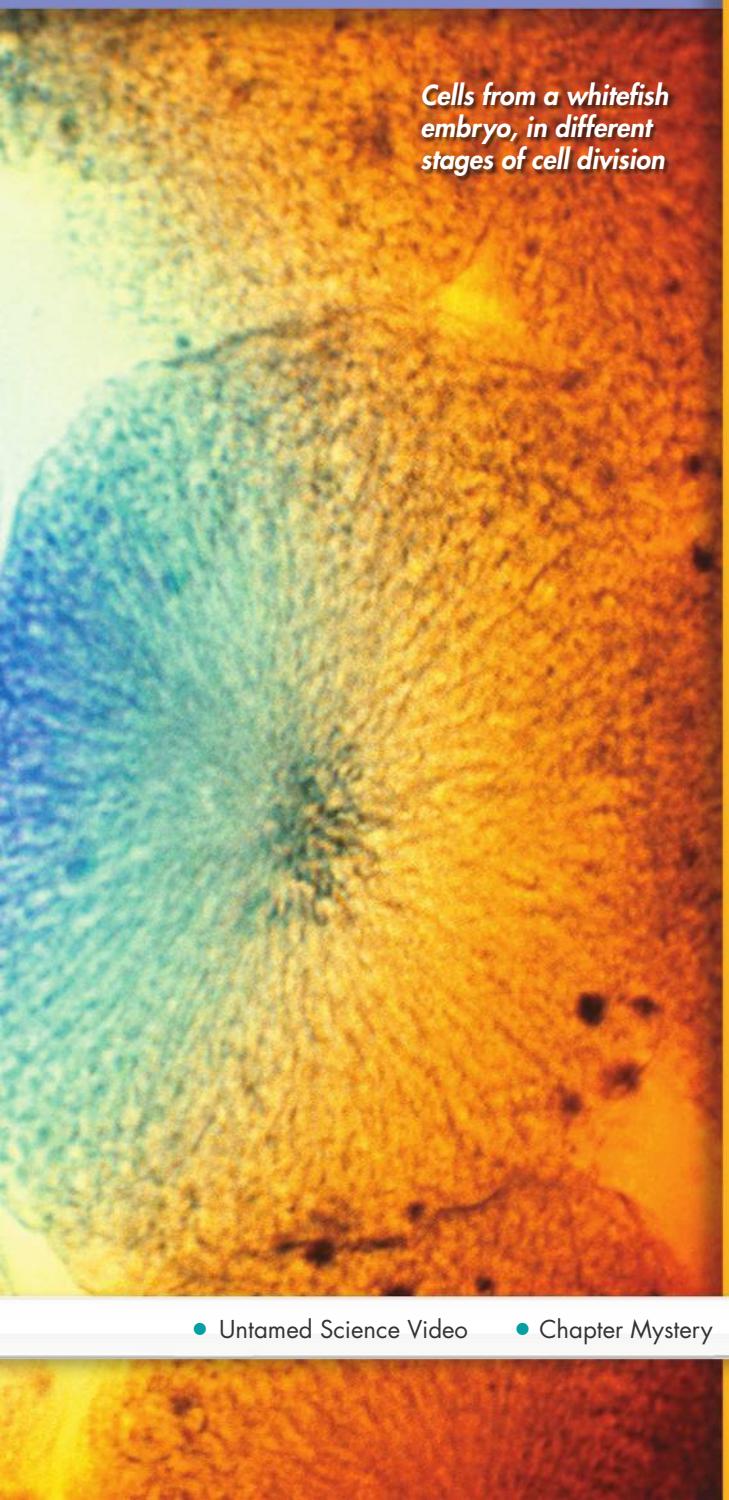
Growth, Development, and Reproduction

Q: How does a cell produce a new cell?



BIOLOGY.com Search Chapter 10 GO • Flash Cards

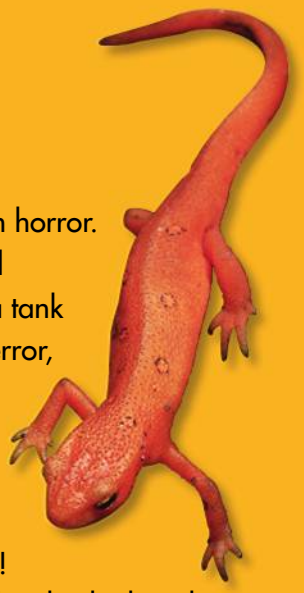
INSIDE:



Cells from a whitefish embryo, in different stages of cell division

- Untamed Science Video
- Chapter Mystery

CHAPTER MYSTERY



PET SHOP ACCIDENT

Julia stared into the salamander tank in horror. As an assistant in a pet shop, Julia had mistakenly put a small salamander in a tank with a large one. As she realized her error, the large salamander bit off one of the small salamander's legs.

Julia put the injured salamander in its own tank. She was sure it would die before her shift ended. She was wrong! Days and weeks passed. Every time Julia checked on the salamander, she was amazed. How did the salamander's body react to losing a limb?

Read for Mystery Clues As you read this chapter, look for clues to help you predict what will happen to the salamander. Think about the cell processes that might be involved. Then, solve the mystery at the end of the chapter.

FOUNDATIONS for Learning

Think of the key vocabulary as building blocks for the Big Idea. Before your read the chapter, write each vocabulary term on an index card. Then write a definition in your own words as you read each lesson. As shown below, you can put the cards into categories to help you remember their meaning. At the end of the chapter are two activities that use the cards to help answer the question: How does a cell produce a new cell?

Process	Cell structures	Not sure
mitosis	chromosome	cyclin
cytokinesis	chromatid	tumor
cell division		

10.1 Cell Growth, Division, and Reproduction

Key Questions

- ***What are some of the difficulties a cell faces as it increases in size?***
- ***How do asexual and sexual reproduction compare?***

BUILD Understanding

T-Chart As you read the lesson, make a T-chart. Start with a two-column chart. In the left column, write the headings in the lesson. In the right column, rewrite the headings as questions. Then, write an answer to each question in the space beneath the question.

In Your Workbook Go to your workbook to learn more about making a T-chart. Complete the T-chart for Lesson 10.1.

Limits to Cell Size

Cells grow bigger, just as you do. However, most cells will grow only so big, then divide. There are two main reasons why cells divide instead of continuing to grow. First, the larger a cell becomes, the more demands the cell has on its DNA. Second, a large cell has more trouble moving enough food in and enough waste out.

Information "Overload" The information that cells need to live and grow is stored in a molecule called deoxyribonucleic acid, or DNA. When a cell is small, its DNA can meet all of its needs. However, as a cell grows, its DNA does not. If a cell grew too large, the result would be "information overload." A cell's DNA could not keep up with the cell's need for information.

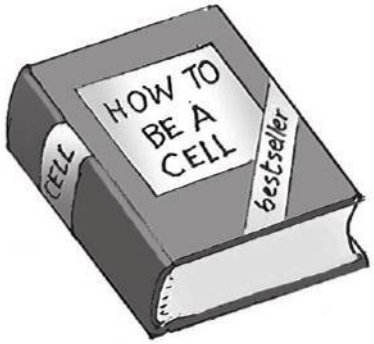
You can compare the cell to a growing town. Suppose a small town has a library with a few thousand books. If more people move into the town, more people will borrow books. Sometimes people may have to wait to borrow popular books. Just like the town, a larger cell would need more from its genetic "library" (DNA). After a while, the DNA would not be able to meet the needs of the growing cell—it might be time to build a new "library."

Exchanging Materials Cell size affects how well a cell can move materials in and out. Food, oxygen, and water enter a cell through its cell membrane. Waste products leave a cell in the same way. The larger a cell becomes, the more nutrients it needs and the more waste it produces. But as a cell grows, the relationship between the surface area of its cell membrane and the size of its volume changes. This change is another reason why cell size is limited.

BUILD Connections

READING DNA

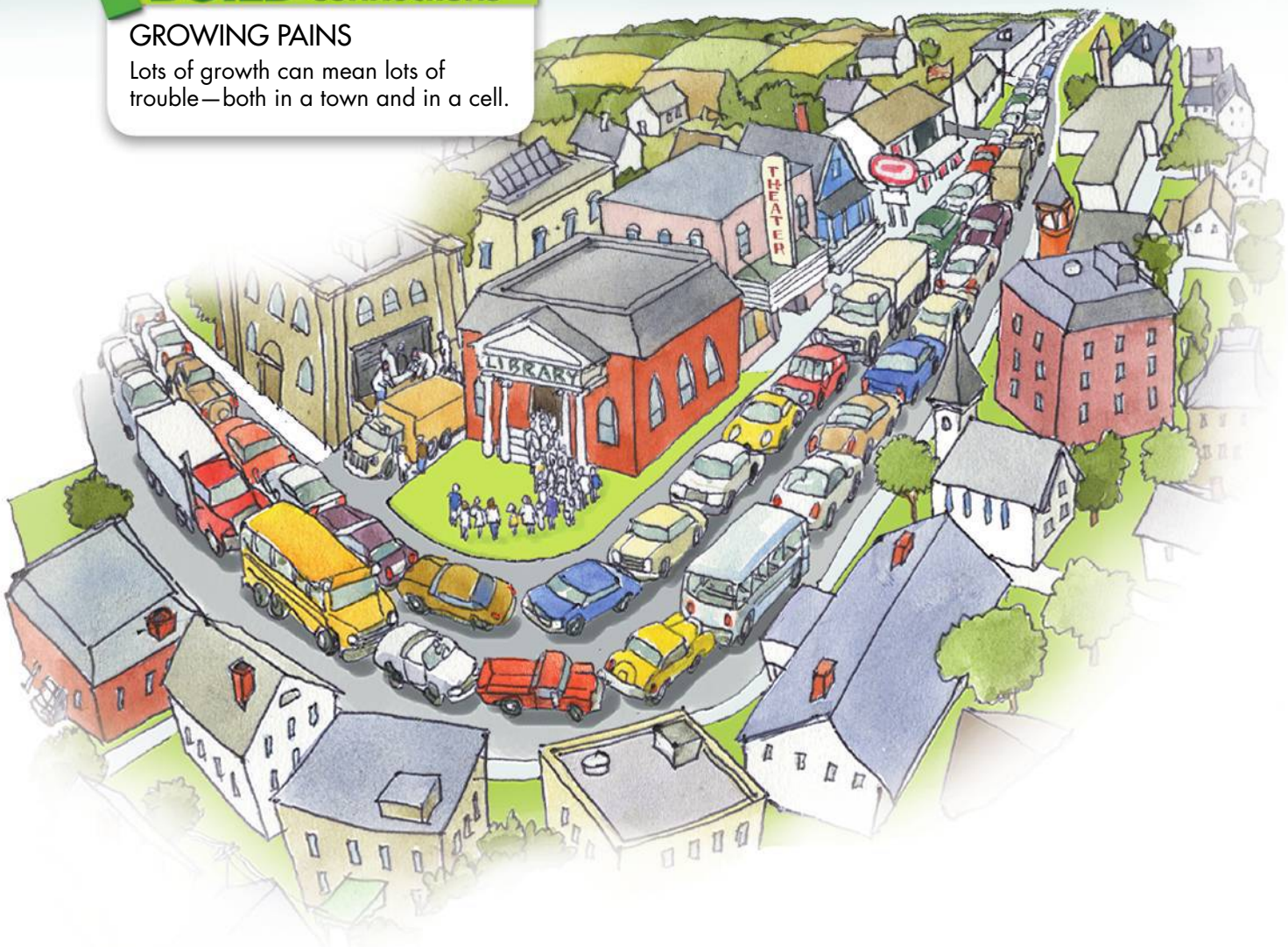
Like a book, DNA contains information. A cell cannot survive without the information stored in its DNA.



BUILD Connections

GROWING PAINS

Lots of growth can mean lots of trouble—both in a town and in a cell.



▶ ***Ratio of Surface Area to Volume*** As a cell grows, the size of its cell membrane does not grow as fast as its volume. To see how, picture a cell as a cube. In a cube with sides that measure 1 cm in length, the ratio of surface area to volume is 6/1 or 6 to 1. Increase the length to 3 cm. The ratio becomes 54/27 or 2 to 1. The ratio of surface area to volume gets smaller. For a growing cell, this difference means the cell has more trouble moving enough food in and all its waste out.

▶ ***Traffic Problems*** Think of the example of the town again. Suppose the town only has a two-lane main street. As the town grows, more people use this street. The increase in traffic means it takes longer to move in and out of the town. A cell that continues to grow would experience similar problems.

Key Question What are some of the difficulties a cell faces as it increases in size?

A cell's DNA may not be able to meet all of its information needs. Also, a large cell has trouble moving enough nutrients in and wastes out.

BUILD Vocabulary

cell division
a process by which a cell divides into two new daughter cells

asexual reproduction
a process by which a single parent reproduces by itself

sexual reproduction
a process by which two cells from different parents fuse, or join together, to produce the first cell of a new organism

PREFIXES

The prefix *a-* in *asexual* means "without." *Asexual reproduction* is reproduction without the fusion of cells.

Cell Division and Reproduction

Before it becomes too large, a growing cell divides. The two new cells are referred to as "daughter" cells. The process by which a cell divides into two cells is called **cell division.**

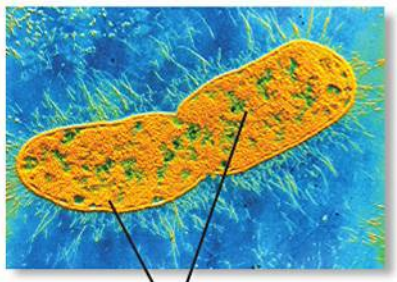
During the process of cell division, a cell makes a copy of its DNA. Each daughter cell gets its own copy. This copying solves the problem of information overload. Cell division also decreases a cell's volume, which allows for a better exchange of materials in and out of the cell. Cell division can also result in reproduction. Reproduction is the process by which organisms produce offspring—new organisms.

Asexual Reproduction For an organism made up of just one cell, cell division may be the only form of reproduction it needs. All the organism has to do is to copy its DNA and then divide. Reproduction by a single parent is called **asexual reproduction.** Offspring of asexual reproduction have the same genetic information as their parent.

Many multicellular organisms reproduce asexually. Hydras are small animals that live in ponds. They reproduce asexually by budding. As cells divide, the bud grows. The bud eventually separates from the parent. A budding hydra is shown below.

Sexual Reproduction Another way for an organism to reproduce is by **sexual reproduction.** Sexual reproduction results from the joining of two cells. Each cell comes from a different parent. Offspring of sexual reproduction have genetic information from both parents. Most animals and plants reproduce sexually. Some single-celled organisms also reproduce sexually. This type of reproduction happens when two cells come together and share DNA.

Asexual Reproduction Cell division leads to reproduction in single-celled organisms and some multicellular organisms.

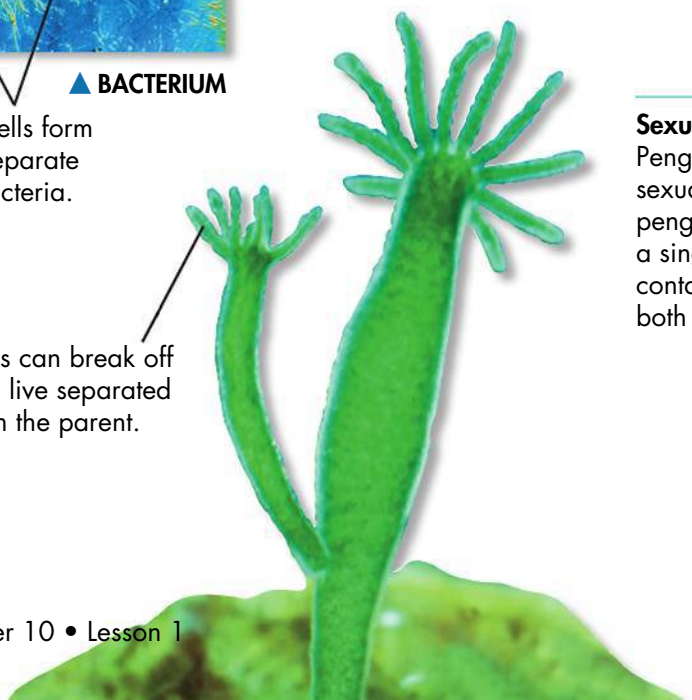


▲ BACTERIUM

Daughter cells form and then separate into two bacteria.

HYDRA

Buds can break off and live separated from the parent.



Sexual Reproduction Penguins reproduce sexually. A baby penguin grows from a single cell that contains DNA from both parents. ▶

Advantages Each method of reproduction has advantages. The main advantages of asexual reproduction are that it is quick and that it produces genetically identical offspring. An organism that is well suited for its environment can reproduce very quickly. The result is a large number of equally well-suited offspring. Asexual reproduction is one reason bacteria are able to grow so quickly when they find themselves in ideal conditions.

The main advantage of sexual reproduction is that offspring are genetically different from their parents. Sexual reproduction lets species "try out" new combinations of genetic information from one generation to the next. If the environment changes rapidly, some members of a species may be able to adjust to those changes.

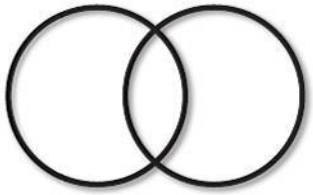
Disadvantages Each method of reproduction also has disadvantages. In asexual reproduction, the lack of genetic diversity can be a disadvantage. Asexually reproducing organisms may not have needed characteristics if their environment changes rapidly. Sexual reproduction is generally slower than asexual reproduction, since it takes two parents instead of one to produce offspring.

Key Question How do asexual and sexual reproduction compare?

Asexual reproduction involves one parent—offspring have the same genetic material as the parent. Sexual reproduction involves two parents—offspring inherit genetic material from both parents.

BUILD Understanding

Venn Diagram Use a Venn diagram to compare and contrast asexual and sexual reproduction.



In Your Workbook Go to your workbook to learn more about making a Venn diagram. Complete the Venn diagram started for you.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. For a growing cell, _____ solves the problems of overloading DNA and not being able to get enough materials in or out.
2. Offspring produced by _____ have a mix of DNA from two parents.
3. Cell division in a single-celled organism is a form of _____.

Critical Thinking

4. **Compare and Contrast** How does DNA in offspring produced by asexual reproduction compare to DNA in offspring produced by sexual reproduction?
5. **Apply Concepts** Describe advantages and disadvantages of asexual reproduction. Describe advantages and disadvantages of sexual reproduction.
6. **Write to Learn** Answer the first clue of the mystery. Write a paragraph that includes the terms *DNA* and *cell division*.

MYSTERY CLUE

As the salamander's wound heals, its body cells are dividing to repair the damage. How is this type of cell division similar to asexual reproduction? (Hint: See p. 236.)

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Modeling the Relationship Between Surface Area and Volume

As a cell grows, its volume increases faster than its surface area. In Lesson 10.1, you saw the relationship between surface area and volume described as a ratio. A ratio is simply a comparison of two numbers. A ratio can be written as a fraction. The table shows how the ratios for 1-cm and 3-cm cubes are calculated.

Look at the calculations for a 3-cm cube.

- First, you calculate the surface area. The formula for the surface area of a cube is

  (length × width) × 6 sides
  (3 cm × 3 cm) × 6 = 54 cm^2

- Next, calculate the volume. The formula for the volume of a cube is

  length × width × height
  3 cm × 3 cm × 3 cm = 27 cm^3

- Finally, determine the ratio of surface area to volume. Write the ratio as a fraction.

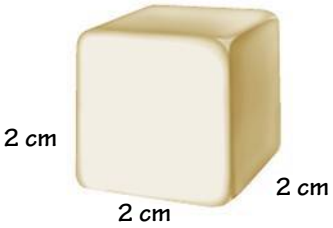
$$\frac{54}{27} = \frac{2}{1}$$

Notice that the fraction 54/27 has been simplified to 2/1. The ratio can also be written as 2 : 1, which is read as "2 to 1."

Analyze and Conclude

1. Predict How would the ratio for a 2-cm cube compare to cubes of 1 cm and 3 cm?

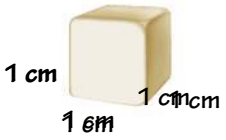
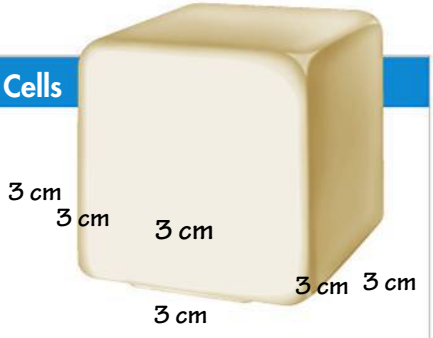
2. Calculate Use the formulas in the table to calculate the ratio of surface area to volume for a 2-cm cube. How accurate was your prediction?



SA = 2 cm × 2 cm × 6 = _____ cm^2
V = 2 cm × 2 cm × 2 cm = _____ cm^3
Ratio = _____ : _____

In Your Workbook Get more help for this activity in your workbook.

Ratio of Surface Area to Volume in Cells

Cell Size		
Surface Area (length × width) × 6 sides	1 cm × 1 cm × 6 = 6 cm^2	3 cm × 3 cm × 6 = 54 cm^2
Volume length × width × height	1 cm × 1 cm × 1 cm = 1 cm^3	3 cm × 3 cm × 3 cm = 27 cm^3
Ratio of Surface Area to Volume	6/1 = 6 : 1	54/27 = 2 : 1

10.2 The Process of Cell Division

Chromosomes

Cells carry genetic information in DNA molecules. Even small cells like the bacterium *E. coli* are packed with DNA. In fact, the total length of the DNA molecule in *E. coli* is almost 1000 times the length of the cell. Clearly, that DNA has to be folded into the cell very carefully. Cells do this by packaging each molecule of DNA into a structure called a **chromosome.** Chromosomes make it possible to separate DNA precisely during cell division.

Prokaryotic Chromosomes Prokaryotic cells, such as *E. coli*, do not have a nucleus. The DNA molecules of prokaryotic cells are found in the cytoplasm. Usually, the genetic material is contained in a single, circle-shaped chromosome.

Eukaryotic Chromosomes The DNA molecules of eukaryotic cells are found in the cell nucleus. You are a eukaryote, as are all other animals and all plants. Eukaryotic cells have much more DNA than prokaryotes. And they package it into many chromosomes. The cells in your body have 46 chromosomes.

The chromosomes in eukaryotic cells form a close relationship with special proteins called histones. This combination of chromosomes and proteins is called **chromatin** (KROH muh tin). As a cell gets ready to divide, chromatin condenses, and individual chromosomes become visible inside the cell.

Key Question What is the job of chromosomes in cell division?

Chromosomes make it possible to separate DNA precisely during cell division.

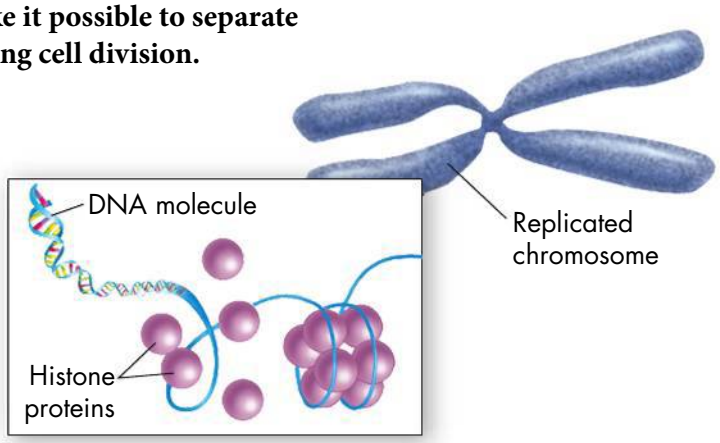
Key Questions

- ***What is the job of chromosomes in cell division?***
- ***What are the main events of the cell cycle?***
- ***What events occur during each phase of mitosis?***
- ***How do daughter cells split apart after mitosis?***

BUILD Understanding

Two-Column Chart Use a two-column chart to take notes on the cell cycle. List the phases of the cell cycle in the first column. Describe the phases in the second column. Draw pictures to help you remember.

In Your Workbook Refer to your workbook for suggestions about how to use a two-column chart to organize your notes.



Eukaryotic Chromosome Histone proteins help to keep long molecules of DNA organized in eukaryotic cells. Before a cell divides, DNA molecules form into tighter and tighter coils that take the form of a chromosome.

BUILD Vocabulary

chromosome
a threadlike structure that contains the genetic information that is passed from one generation of cells to the next

chromatin
a substance found in eukaryotic chromosomes that consists of DNA tightly coiled around histones

cell cycle
a series of events a cell goes through as it grows and divides

WORD ORIGINS

The words *cycle* and *circle* share the same root, *kyklos*, a Greek word meaning "wheel." Cycles are often drawn as circles because they are a series of events that repeat—or go around again and again.

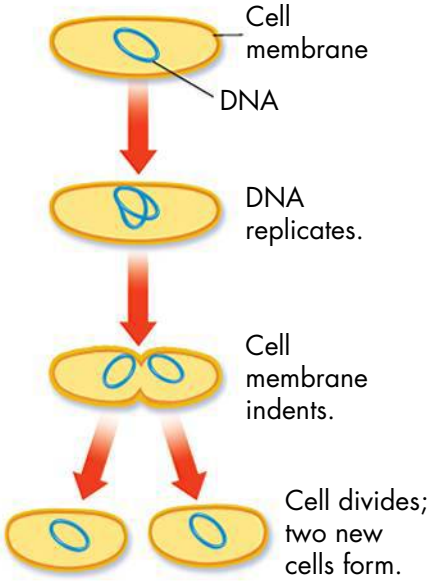
The Cell Cycle

Cells go through a series of events as they grow and then divide. Altogether, these events are called the **cell cycle.** During the cell cycle, a cell grows, prepares for division by making a copy of its DNA, and then divides to form two daughter cells. Each daughter cell then begins the cycle again.

Before any cell divides, it must copy, or replicate, its DNA. What this means, of course, is that the cell must make, or synthesize, new strands of DNA so that each cell receives a complete set of genetic information.

The Prokaryotic Cell Cycle The prokaryotic cell cycle includes cell growth, DNA replication, and cell division. Cell division can happen quickly under good conditions. Most prokaryotic cells replicate, or copy, their DNA once they have grown to a certain size. When DNA replication is complete, or almost complete, the cell begins to divide. The process of cell division in prokaryotes is a form of asexual reproduction called binary fission.

After the chromosome is replicated, the two DNA molecules attach to different parts of the cell membrane. A group of fibers form between the molecules. As the fibers tighten, the cell is pinched across its center. The tightening fibers divide the cytoplasm and separate the cell into two cells. Binary fission results in two cells with the same genetic material.



Binary Fission
Cell division in a single-celled organism produces two genetically identical organisms.

The Eukaryotic Cell Cycle The eukaryotic cell cycle has four parts or phases: G_1, S, G_2, and M. The period of growth between cell divisions is referred to as **interphase.** It includes G_1, S, and G_2. A cell prepares to divide during the fourth phase M. At the end of M phase, the cell divides into two daughter cells. The cycle begins again. Refer to the figure below as you read the description of each phase of the eukaryotic cell cycle.

▶ ***G_1 Phase: Cell Growth*** A cell does most of its growing during the G_1 phase. It increases in size and produces new proteins and organelles. The G in G_1 and G_2 stands for "gap." However, both G phases are periods of growth and activity.

▶ ***S Phase: DNA Replication*** The G_1 phase is followed by the S phase. The S stands for "synthesis." During the S phase, new DNA is synthesized when chromosomes are replicated.

▶ ***G_2 Phase: Preparing for Cell Division*** When DNA replication is complete, a cell enters the G_2 phase. During this phase, many of the organelles and molecules needed for cell division are produced. At the end of the G_2 phase, a cell is ready to begin the process of cell division.

▶ ***M Phase: Cell Division*** The M in M phase stands for **mitosis** (my TOH sis). Mitosis is the first stage of the M phase, a series of events that lead to the division of the cell nucleus. **Cytokinesis** (sy toh kin NEE sis) is the second stage. It ends with the division of the cytoplasm. At the end of the M phase, two new daughter cells begin the cycle again.

Key Question What are the main events of the cell cycle?

During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells. The eukaryotic cell cycle has two parts: interphase and cell division.

BUILD Vocabulary

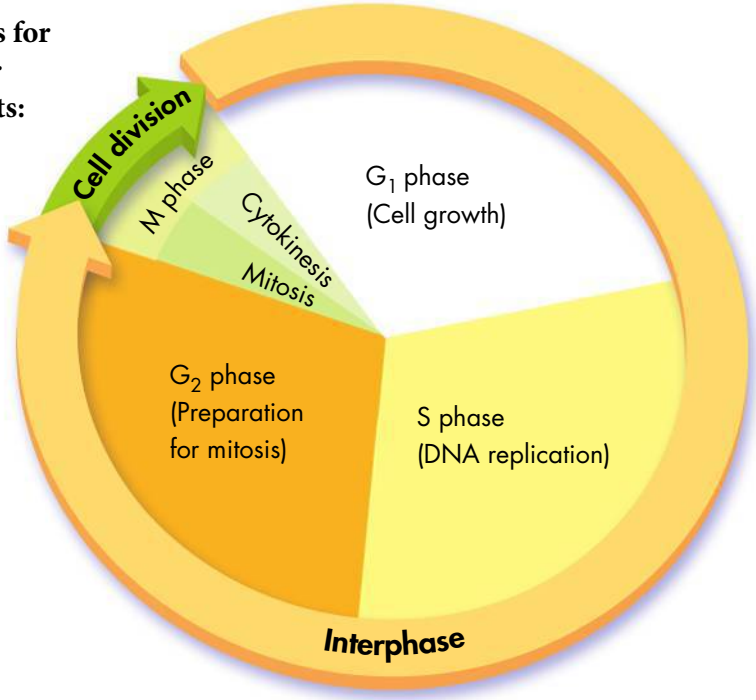
interphase
a long period of the cell cycle between one cell division and the next

mitosis
the part of the eukaryotic cell cycle during which the nucleus divides

cytokinesis
the part of the eukaryotic cell cycle during which the cytoplasm divides

PREFIXES

The prefix *cyto-* is a word part that has come to mean "cell." It comes from a Greek word *kytos* that means "hollow vessel." It is used in *cytokinesis* and *cytoplasm*. The first people to see cells using a microscope thought that cells were empty.



Eukaryotic Cell Cycle
The length of the yellow arrow indicates that eukaryotic cells spend most of their time in interphase. Cell division happens quickly.

BUILD Vocabulary

chromatid
one of two identical "sister" parts of a replicated chromosome

centromere
an area where two sister chromatids are attached

WORD ORIGINS

Both *centromere* and *centriole* have the word part *cent-*, which is similar to the word *center*. The Latin word *centrum* means "center."

Mitosis

Mitosis is divided into four phases: prophase, metaphase, anaphase, and telophase. Refer to the figure below as you read about the phases of mitosis.

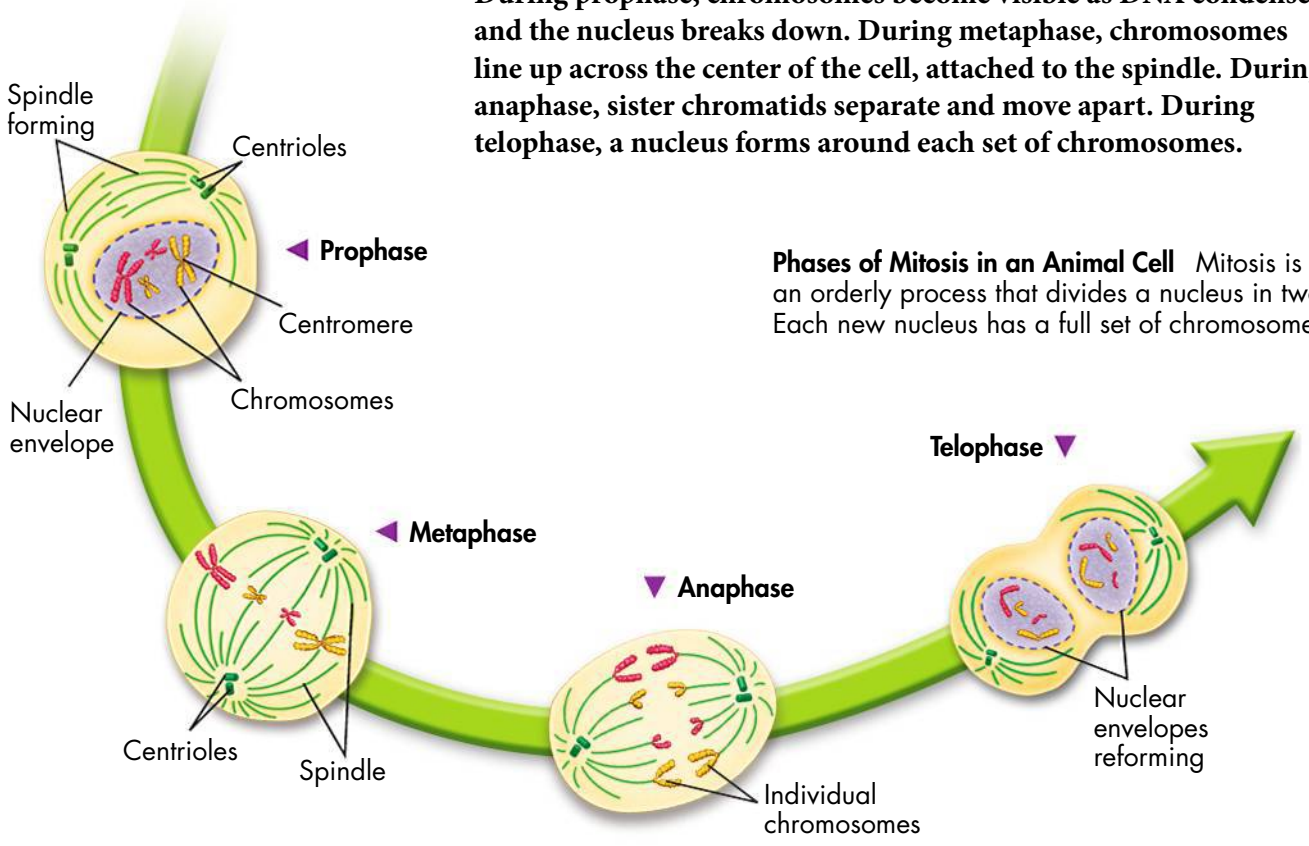
Prophase Prophase is the first phase of mitosis. The replicated chromosomes become visible as DNA starts to condense. Each strand of DNA in a doubled chromosome is called a **chromatid.** The sister chromatids are joined at an area called the **centromere.** The nuclear envelope breaks down, and a spindle begins to form. A pair of structures called centrioles help to organize the spindle fibers.

Metaphase The second phase of mitosis is metaphase. The chromosomes line up at the center of the cell. Spindle fibers connect the centromere of each chromosome to the spindle.

Anaphase Anaphase is the third phase of mitosis. The centromeres split, and the sister chromatids separate. A complete set of chromosomes move to opposite sides of the cell.

Telophase The fourth and final phase is telophase. The chromosomes spread out into a tangle of chromatin. A nuclear envelope reforms around each group of chromosomes. The spindle begins to break apart. Mitosis is complete, but cell division still has one more step to go.

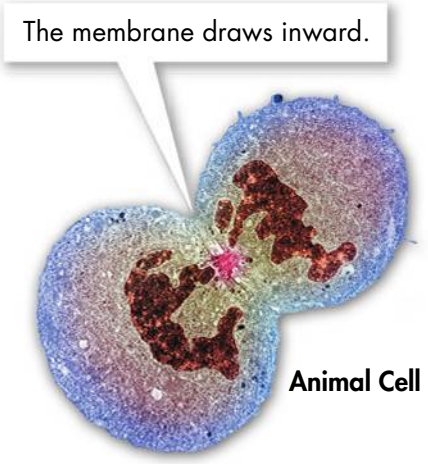
Key Question What events occur during each phase of mitosis?
During prophase, chromosomes become visible as DNA condenses and the nucleus breaks down. During metaphase, chromosomes line up across the center of the cell, attached to the spindle. During anaphase, sister chromatids separate and move apart. During telophase, a nucleus forms around each set of chromosomes.



Phases of Mitosis in an Animal Cell Mitosis is an orderly process that divides a nucleus in two. Each new nucleus has a full set of chromosomes.

Cytokinesis

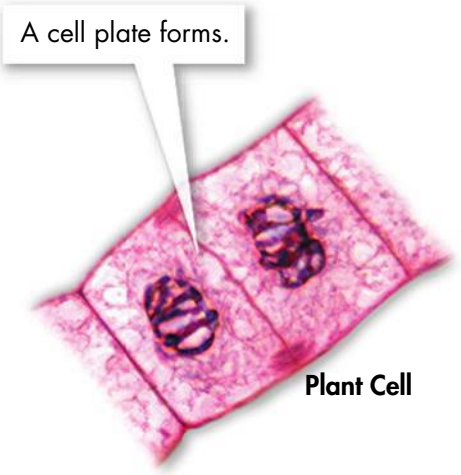
Mitosis produces two nuclei, each with a complete set of chromosomes. All that is left to complete the M phase is the division of the cytoplasm. Cytokinesis completes cell division by splitting one cell into two daughter cells. The process is different in animal and plant cells.



Cytokinesis
The division of the cytoplasm occurs differently in animal cells and plant cells.

Cytokinesis in Animal Cells In animal cells, the cell membrane is pulled toward the center of the cell. Eventually the cytoplasm is divided into two nearly equal parts. Each part contains its own nucleus and organelles.

Cytokinesis in Plant Cells In plant cells the cell membrane is attached to a stiff cell wall. It is not flexible enough to pinch in. Instead a cell plate forms between the two nuclei. The cell plate develops into cell membranes that separate the two daughter cells. Next, a cell wall forms between the two new membranes. Each part contains its own nucleus and organelles.



Key Question How do daughter cells split apart after mitosis?
Cytokinesis divides the cytoplasm, splitting one cell into two. In animal cells, the cell membrane pinches in. In plant cells, a cell plate forms.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. In prokaryotes, most cells have a single _____ that contains all the genetic material.
2. In eukaryotes, DNA and proteins combine to form _____.
3. The cell cycle of a eukaryote is divided into two stages: _____ and cell division.
4. In a eukaryotic cell, the chromosomes divide and separate during _____.

Critical Thinking

5. **Sequence** Draw a flowchart that follows a chromosome through a complete eukaryotic cell cycle.
6. **Compare and Contrast** How is cytokinesis in animals and plant cells alike and different?
7. **Write to Learn** Answer the second clue of the mystery. Think about what happens when you cut your finger. How quickly does your body repair the skin? What does that suggest?

MYSTERY CLUE

How would you expect the salamander's wound to affect the cell cycle of the cells that surround the wound? (Hint: See p. 241.)

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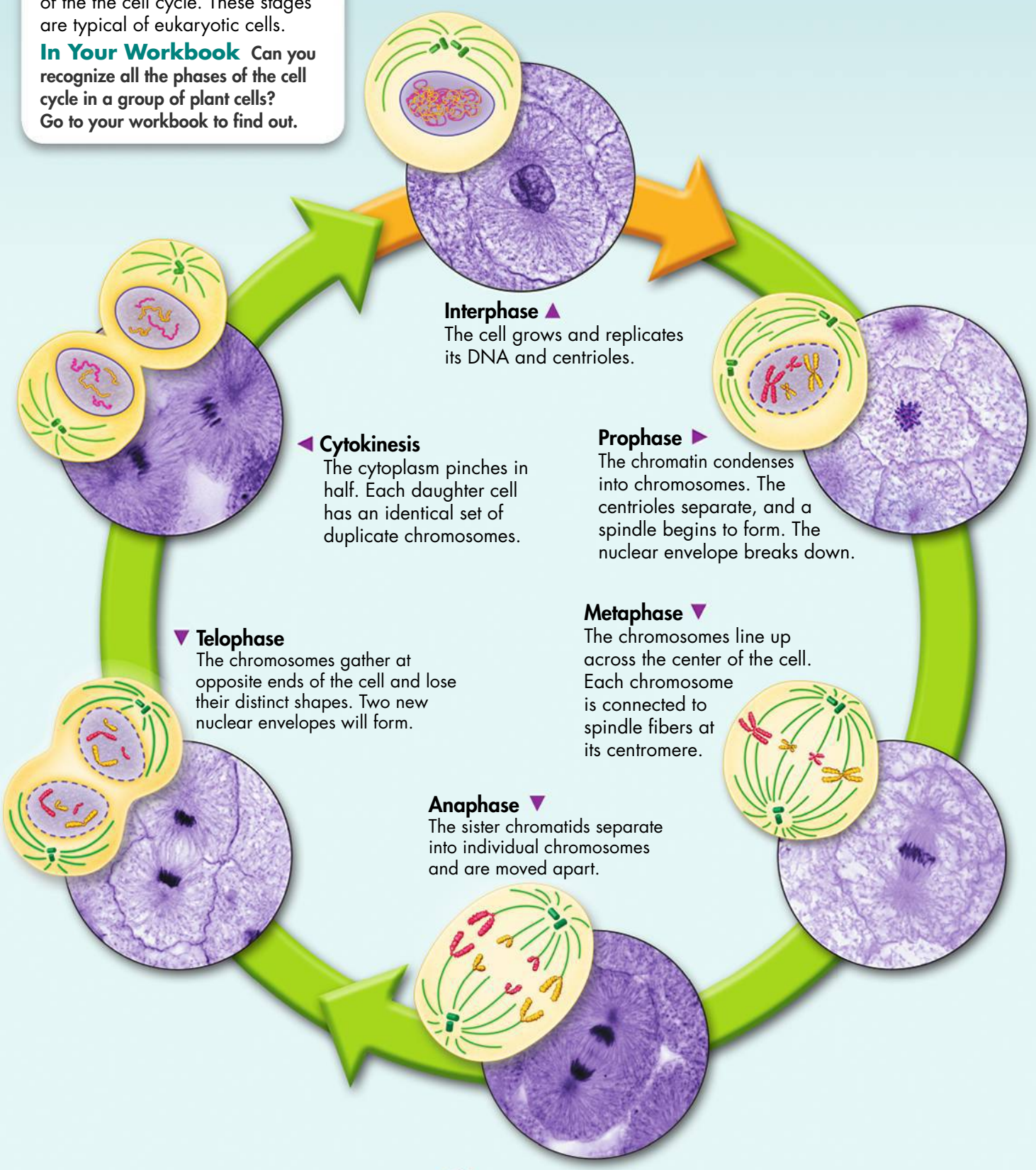
BUILD Connections

THE CELL CYCLE

The phases of mitosis and cytokinesis are shown here as part of the the cell cycle. These stages are typical of eukaryotic cells.

In Your Workbook **Can you recognize all the phases of the cell cycle in a group of plant cells? Go to your workbook to find out.**



Interphase ▲
The cell grows and replicates its DNA and centrioles.

Prophase ►
The chromatin condenses into chromosomes. The centrioles separate, and a spindle begins to form. The nuclear envelope breaks down.

Metaphase ▼
The chromosomes line up across the center of the cell. Each chromosome is connected to spindle fibers at its centromere.

Anaphase ▼
The sister chromatids separate into individual chromosomes and are moved apart.

▼ Telophase
The chromosomes gather at opposite ends of the cell and lose their distinct shapes. Two new nuclear envelopes will form.

◄ Cytokinesis
The cytoplasm pinches in half. Each daughter cell has an identical set of duplicate chromosomes.

10.3 Regulating the Cell Cycle

Controls on Cell Division

The cell cycle is a process cells go through as they grow and divide. In multicellular organisms, the cell cycle is carefully controlled. In your body, for example, skin cells grow and divide quickly. However, most of the cells in your muscles and nerves do not grow and divide. How do cells know when to divide?

Some cells respond to outside signals. For example, cells grown in a small culture dish will stop growing and dividing when they touch other cells. What happens when cells are removed from the dish? The remaining cells begin to grow and divide again. They stop again when they come in contact with other cells.

Something like this happens in your body when you cut your skin or break a bone. The cells at the edges of the injury begin to divide quickly. These new cells allow the injury to heal. When the healing process is almost done, the rate of cell division slows down. The cell cycle returns to normal.

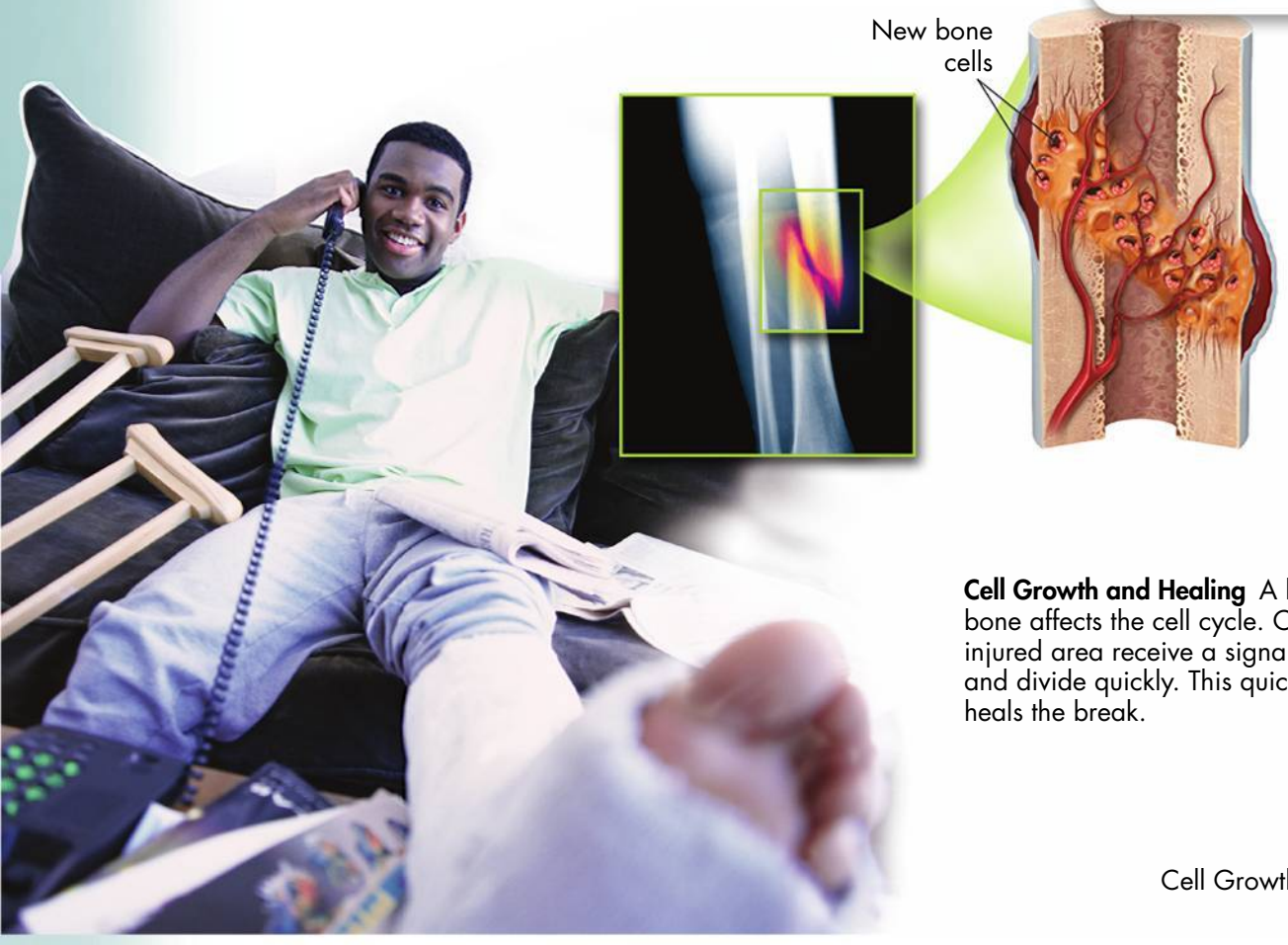
Key Questions

- ***How is the cell cycle regulated?***
- ***How do cancer cells differ from other cells?***

BUILD Understanding

Concept Map Make a concept map to organize the information in the lesson. Start with the heading "Regulating the Cell Cycle." Then add the smaller blue headings.

In Your Workbook Go to your workbook for help in completing the concept map.



Cell Growth and Healing A broken bone affects the cell cycle. Cells in the injured area receive a signal to grow and divide quickly. This quick growth heals the break.

BUILD Vocabulary

growth factor
an external regulatory protein that stimulates the growth and division of cells

apoptosis
a process in which a cell is programmed to die

cancer
a disorder in which some of the body's own cells lose the ability to control growth

ACADEMIC WORDS

In the term *growth factor*, the word *factor* means "something that contributes to a result or a process." Growth factors contribute to many processes, including the healing of broken bones.

Regulatory Proteins For many years, biologists searched for the signals that controlled the cell cycle. They have found many different proteins that regulate, or control, the cell cycle.

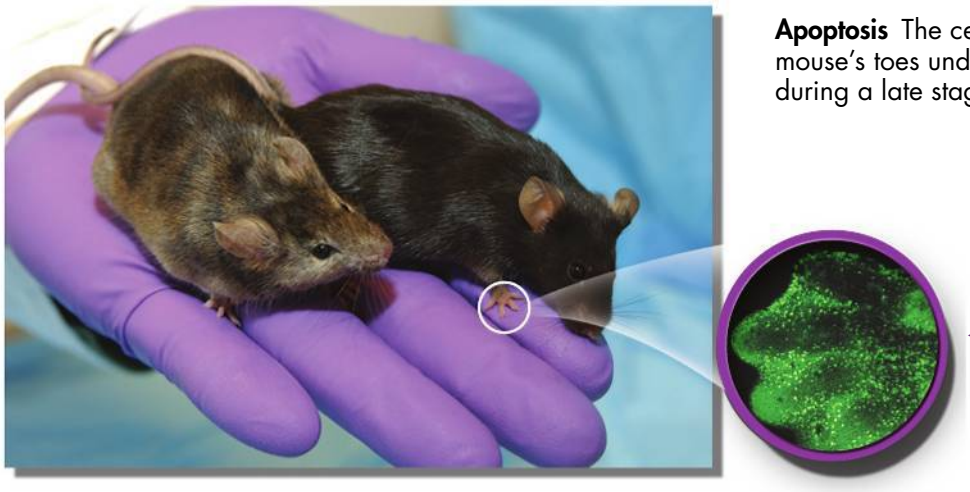
▶ ***External Regulators*** Proteins that respond to events outside the cell are called external regulators. External regulators can cause the cell cycle to speed up or slow down. **Growth factors** are important external regulators. Growth-factor proteins control the cell cycle when you have an injury, such as a broken bone. They are also involved in controlling the cell cycle during the development of an embryo.

▶ ***Internal Regulators*** Proteins that respond to events inside the cell are called internal regulators. Internal regulators control the stages of the cell cycle. For example, internal regulators make sure that chromosomes have been replicated before mitosis starts. One important group of regulatory proteins are called cyclins. Cyclins regulate the timing of the cell cycle in eukaryotic cells.

Apoptosis Your body is producing new cells every day. Your body is also removing cells every day. Some cells die by accident because of damage or injury. Other cells, such as skin cells, are "programmed" to die. The process that brings an end to the cell cycle is called **apoptosis** (AYP up TOH sis). During apoptosis, a cell goes through a series of steps that lead to its death.

Apoptosis shapes the structure of tissues and organs in plants and animals. For example, look at the photos of a mouse foot below. Compare the shape of the embryonic foot to the adult foot. Cells between the mouse's toes are programmed to die during tissue development. The cells that remain form into toes.

Key Question How is the cell cycle regulated?
The cell cycle is controlled by regulatory proteins both inside and outside the cell.



Apoptosis The cells between a mouse's toes undergo apoptosis during a late stage of development.

◀ Embryonic foot (TEM 50X)

Cancer: Uncontrolled Cell Growth

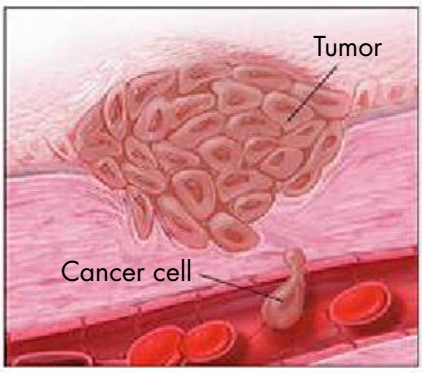
Cancer is a disorder that shows what happens when cell growth is not controlled. Cancer develops when the body loses the ability to control growth in some of its cells. Cancer cells divide without control because they do not respond to the signals that regulate the cell cycle.

Cancerous Tumors Cancer cells form into a mass of cells called a tumor. The cancer cells can spread to nearby tissues and to other parts of the body. As cancer cells grow and divide, they use more and more of the nutrients needed by healthy cells. They can also prevent organs and tissues from functioning normally. Not all tumors are cancerous.

What Causes Cancer? Cancers are caused by damage to a cell's DNA. The damage, or defect, occurs in that part of the genetic material that regulates cell growth and division. Some of these defects are caused by tobacco smoking, radiation exposure, and viral infection.

Treatments for Cancer If a tumor is found early, doctors can often remove it with surgery. Skin cancer can usually be treated this way. In addition, beams of radiation can kill cancer cells. Doctors can also treat cancer with chemical compounds that kill or slow the growth of cancer cells. This treatment is called chemotherapy.

Key Question How do cancer cells differ from other cells?
Cancer cells do not respond to the signals that regulate the growth of most cells. As a result, cells divide uncontrollably.



Cell Growth and Cancer Cancer starts when a cell begins to divide without control. A tumor forms. Cancer cells are dangerous because they can get into the bloodstream. From there, they can spread throughout the body.

CHECK Understanding

Use the highlighted words from the lesson to complete each sentence correctly.

1. _____ is a normal process that causes a cell to die.
2. Abnormal cells that do not die but continue to grow and divide cause _____.
3. External regulatory proteins that increase the rate of cell division during an organism's development are called _____.

Critical Thinking

4. **Infer** Why is cancer considered a disease of the cell cycle?
5. **Apply Concepts** How would the pattern of apoptosis differ in a duck's webbed foot compared to the pattern of apoptosis in a mouse's foot?
6. **Explain** What are cyclins? What do cyclins do?
7. **Write to Learn** Answer the third clue of the mystery. The image of the broken bone on the first page of this lesson will help you answer the question.

MYSTERY CLUE

How might regulatory proteins be involved in wound healing in the salamander? (Hint: See p. 246.)

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10.4 Cell Differentiation

Key Questions

- ***How do cells become specialized for different functions?***
- ***What are stem cells?***
- ***What are some possible benefits and issues associated with stem cell research?***

BUILD Understanding

Compare/Contrast Table
Certain types of cells have the ability to differentiate. Use a table to write what you learn about these cells.

In Your Workbook Go to your workbook to see how to organize your compare/contrast table.

From One Cell to Many

Each of us started life as just one cell—a single fertilized egg. So did your pet dog or cat. The fertilized egg goes through an early stage of development called an **embryo.** As it grows, the embryo develops and changes. During the development process, the embryo's cells become different from one another. They differentiate.

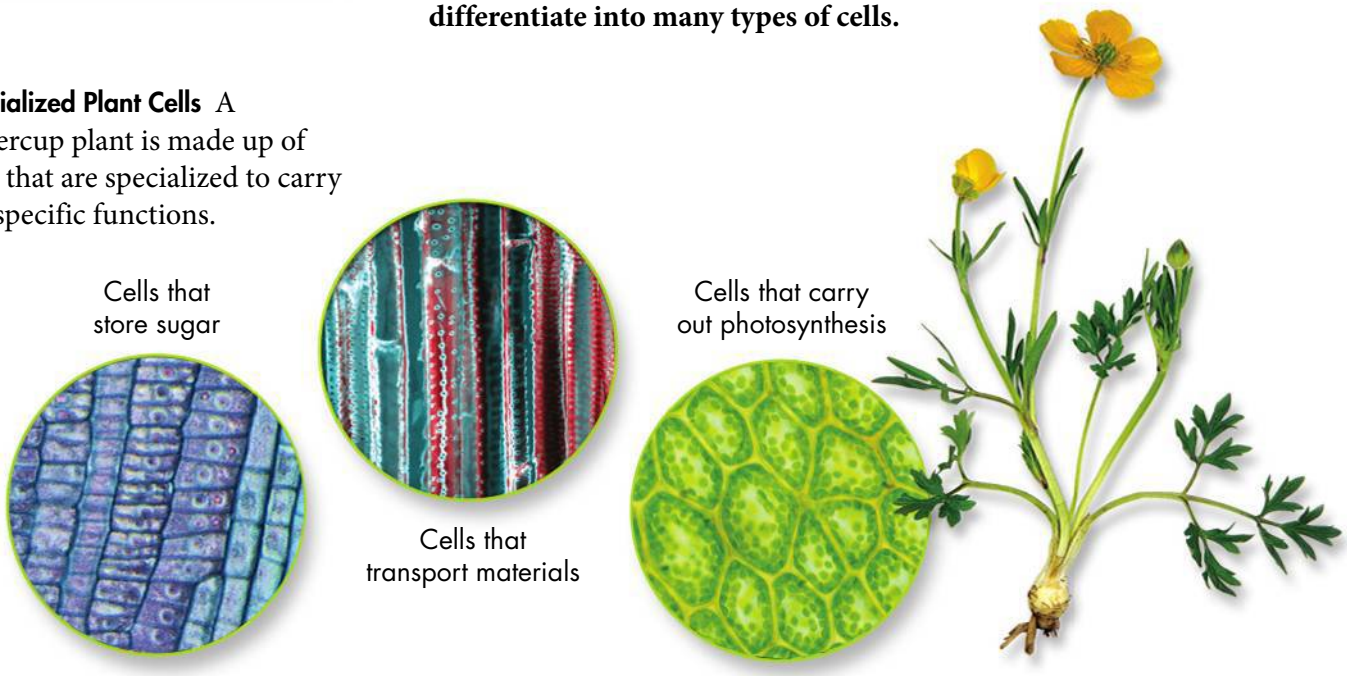
What Is Differentiation? Cells become specialized through the process of **differentiation.** Your body has more than 200 different cell types. Notice that the word *differentiate* contains the word *different*. A differentiated cell has become different from the original cell that produced it.

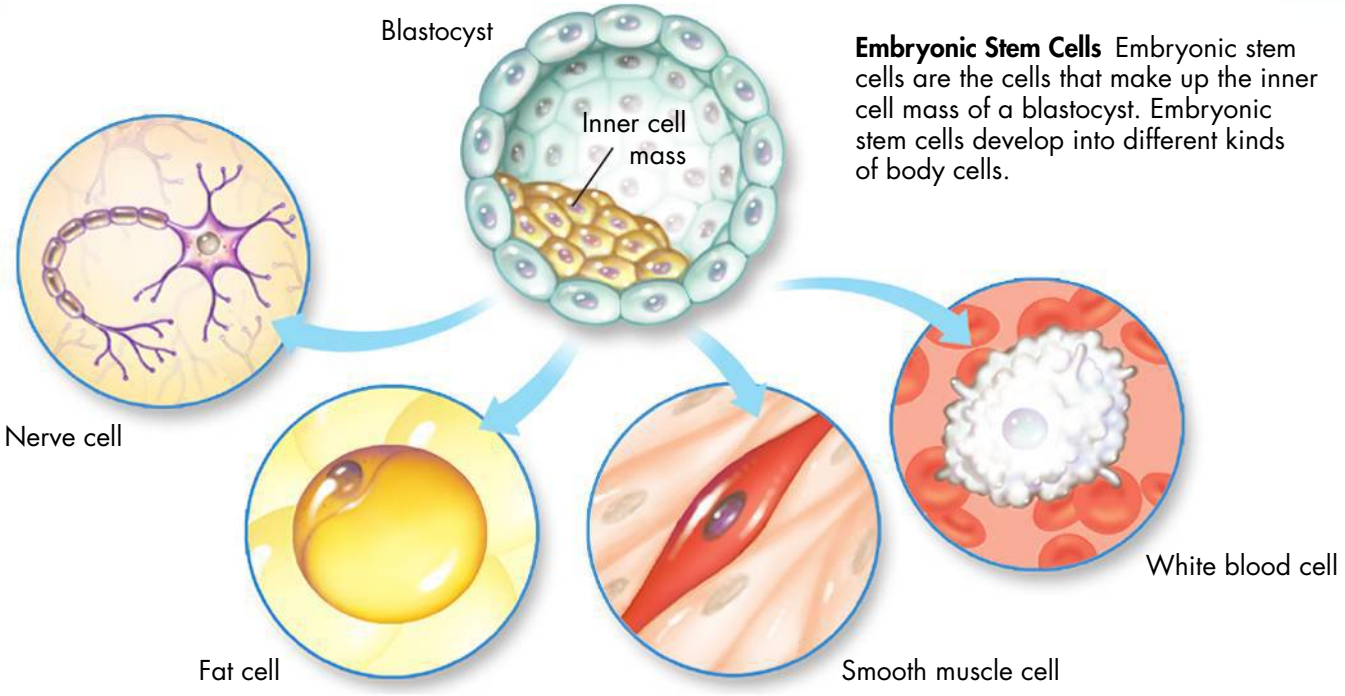
What Is a Specialized Cell? Differentiated cells are specialized to perform certain jobs. In a plant, for example, some cells carry out photosynthesis. Other plant cells store sugars. Other plant cells create pathways for moving materials up and down. In your body, differentiated cells carry out certain jobs that keep you alive.

Key Question How do cells become specialized for different functions?

During the development of an organism, cells differentiate into many types of cells.

Specialized Plant Cells A buttercup plant is made up of cells that are specialized to carry out specific functions.





Embryonic Stem Cells Embryonic stem cells are the cells that make up the inner cell mass of a blastocyst. Embryonic stem cells develop into different kinds of body cells.

Stem Cells and Development

A fertilized egg divides over and over to form new cells. The fertilized egg and the cells produced by the first few divisions are totipotent. **Totipotent** (toh TIP uh tunt) cells can differentiate into any type of cell.

Human Development Early in development, a human embryo forms into a blastocyst. A blastocyst is a hollow ball of cells with a group of cells inside called the inner cell mass. The outer cells form tissues that attach the embryo to its mother. The inner cell mass becomes the embryo itself.

The cells of the inner cell mass are pluripotent. **Pluripotent** (plu RIP uh tunt) cells can develop into all the types of cells in the body. However, pluripotent cells cannot form the tissues that surround the embryo. Therefore, the cells of the inner cell mass are not totipotent.

Stem Cells Differentiated, specialized cells develop from unspecialized cells known as **stem cells.** Researchers are very interested in stem cells, because stem cells can develop into other types of cells.

▶ ***Embryonic Stem Cells*** The pluripotent cells that make up the early embryo are called embryonic stem cells. They will eventually produce all of the cells in the body. Scientists have experimented with stem cells grown in the laboratory. For example, scientists have been able to get mouse embryonic stem cells to develop into nerve cells, muscle cells, and even into sperm and egg cells.

BUILD Vocabulary

embryo
an organism in its early stage of development

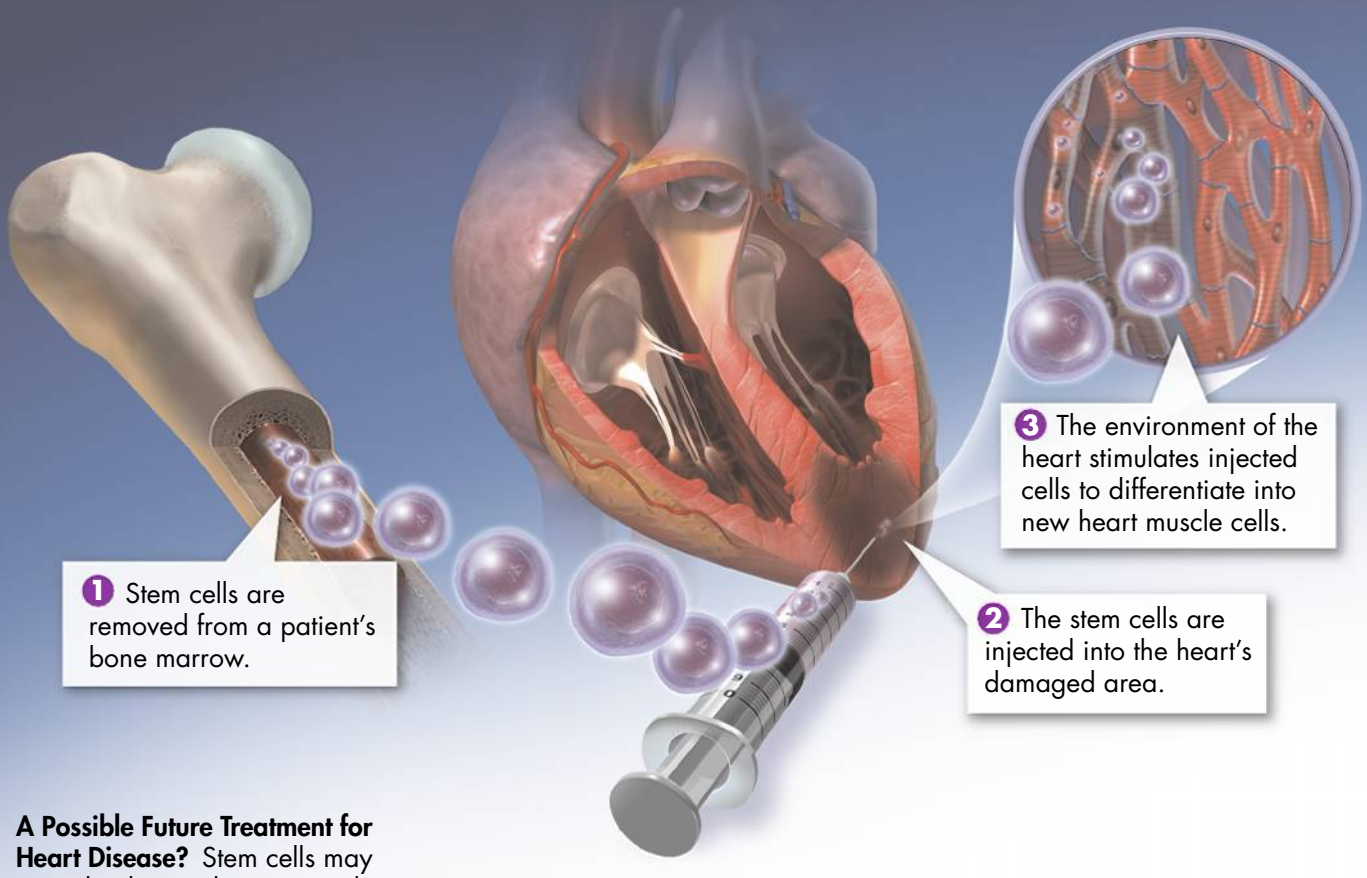
differentiation
a process in which cells become specialized in structure and function

totipotent
having the ability to develop into all the tissues of the body

pluripotent
able to develop into all the body's cell types, but not capable of developing into the tissues surrounding the embryo

PREFIXES

The prefix *toti-* means "all." The word part *potent* means "powerful." A totipotent cell has the power to develop into all the tissues of the body.



A Possible Future Treatment for Heart Disease? Stem cells may someday be used to reverse the damage caused by a heart attack. The diagram shows one method that scientists are investigating.

▶ ***Adult Stem Cells*** Adult organisms also contain some types of stem cells. For example, adult stem cells produce new skin and blood cells. Skin cells and blood cells only live a short time. Therefore, they need to be replaced all the time.

Adult stem cells are called **multipotent** (mul TIP uh tunt) cells. Multipotent means that they can produce many, but not all, types of differentiated cells. For example, adult stem cells in the bone marrow can develop into several types of blood cells.

Key Question What are stem cells?
Stem cells are the unspecialized cells from which differentiated cells develop.

BUILD Vocabulary

stem cell
an unspecialized cell that can give rise to one or more types of specialized cells

multipotent
having the ability to produce many, but not all, kinds of differentiated cells

PREFIXES

The prefix *multi-* means "many." Multipotent cells can differentiate into many types of cells.

Frontiers in Stem Cell Research

Scientists want to learn how stem cells keep the ability to differentiate into so many different types of cells. Scientists would also like to know why some cells in adults stay multipotent, but other cells lose their ability to differentiate.

Possible Benefits Research on stem cells is important. That is because scientists hope that stem cells might improve human health. Someday, stem cells might be used to fix cells that have been damaged. For example, stem cells might be used to repair heart-attack damage.

Ethical Issues Stem cell research may someday help humans. However, people disagree about whether certain kinds of stem cell research is right or wrong.

To obtain embryonic stem cells, scientists must usually destroy the embryo. Some people believe embryos should have the same protections as any person. These people object to research involving embryonic stem cells. Other people support research with embryonic stem cells. They believe it can improve and save human lives.

Scientists are looking for ways to let embryonic stem cell research continue. For example, scientists hope to find a way to remove a few embryonic stem cells without damaging the embryo. In addition, scientists have been able to make adult stem cells act like pluripotent embryonic stem cells.

Key Question What are some possible benefits and issues associated with stem cell research?

Stem cells offer the possible benefit of using undifferentiated cells to repair or replace badly damaged cells and tissues. Human embryonic stem cell research is controversial because it involves issues of life and death.

CHECK Understanding

Apply Vocabulary

Use the highlighted words from the lesson to complete each sentence correctly.

1. A fertilized egg is a _____ cell, since all the different tissues of the body, including those that surround the embryo, develop from it.
2. The process in which cells become specialized to do different jobs is called _____.
3. Early in development, a human _____ forms into a hollow ball of cells called a blastocyst.
4. Specialized body cells develop from embryonic _____ cells.
5. Cells that are _____, such as those that produce skin and blood cells, can develop into some, but not all, types of specialized cells.

Critical Thinking

6. **Interpret Visuals** Look again at the picture called Embryonic Stem Cells. In your own words, describe what the picture shows.
7. **Compare and Contrast** How are totipotent and pluripotent cells alike? How are they different?
8. **Explain** Explain the potential benefits of stem cell research and the problems associated with this research.
9. **Write to Learn** Answer the fourth clue of the mystery. In your answer, explain how undifferentiated cells might be useful to the adult salamander.

MYSTERY CLUE

Some adult salamander cells never completely differentiate. What ability do these cells retain? (Hint: See p. 249.)

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Design Your Own Lab

OPEN-ENDED INQUIRY

Pre-Lab: Regeneration in Planaria

Problem How potent are the stem cells in planaria?

Materials fresh water or spring water, planarians, petri dishes, grease pencil, forceps, scalpel, dissecting microscope, glass microscope slide, lens paper, pipette, small paintbrush, clear ruler

Lab Manual Chapter 10 Lab

Skills Focus Form a Hypothesis, Design an Experiment, Draw Conclusions

Connect to the Big idea All cells come from existing cells. When most cells in a multicellular organism divide, they produce cells just like themselves. However, some cells can differentiate to form different types of cells. These cells enable an organism to repair tissue after an injury or in some cases to regenerate body parts. In this lab, you will investigate the ability of planarians to regenerate body parts.

Background Questions

a. **Compare and Contrast** What is the difference between totipotent stem cells and multipotent stem cells?

b. **Apply Concepts** What type of stem cell enables your body to produce cells, such as skin and blood cells that are constantly replaced by the body?

c. **Apply Concepts** What type of stem cell enables a salamander to regenerate its tail?

d. **Compare and Contrast** In what way is regeneration of a body part similar to asexual reproduction? In what way is it different?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Apply Concepts** What would you expect to observe if the stem cells in planarians are totipotent? What would you expect to observe if the stem cells are multipotent?

2. **Control Variables** What will you use as a control in your experiment? Explain why you need this control.

3. **Infer** Two planarians are cut at different locations. Regeneration occurs in one planarian, but not in the other. Based on these results, what might you infer about stem cells in planarians?

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Visit Chapter 10 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Journey with the Untamed Science crew to a research facility in Sweden to learn why scientists are studying regeneration in brittle stars.

Visual Analogy Compare a growing cell to a growing city to understand limits on cell size.

Tutor Tube Confused about chromosome terminology? Tune in to Tutor Tube to unravel the vocabulary of chromatin.

Art Review Test your knowledge of the structure of a eukaryotic chromosome.

InterActive Art See the phases of mitosis in action.

Art in Motion See what happens when cancerous cells invade normal tissue.

10 CHAPTER Summary

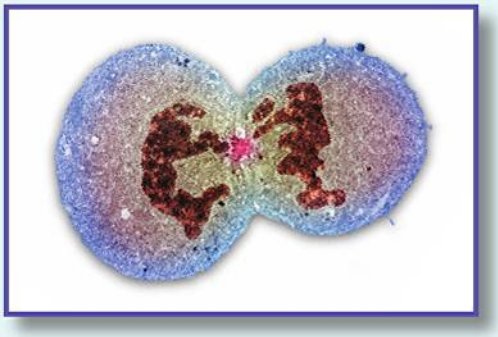
10.1 Cell Growth, Division, and Reproduction

- Cells grow only so big before they divide. The larger a cell becomes, the more demands the cell places on its DNA. Also, a larger cell has more difficulty in moving enough nutrients in and wastes out.
- Organisms produced by asexual reproduction are genetically the same as the single cell that produced them.
- Organisms produced by sexual reproduction grow from a single cell that contains genetic information from two parents.

cell division (p. 236)
asexual reproduction (p. 236)
sexual reproduction (p. 236)

10.2 The Process of Cell Division

- Chromosomes are made up of DNA that carries a cell's genetic information.
- The eukaryotic cell cycle includes interphase, mitosis, and cytokinesis.
- Mitosis is divided into four phases in which replicated chromosomes and a cell's nucleus divide equally. In prophase, the chromosomes condense and the nucleus breaks down. In metaphase, the chromosomes line up at the center of the cell. In anaphase, sister chromatids separate. In telophase, a nucleus reforms around each set of separated chromosomes.
- Cytokinesis completes the process of cell division. It splits one cell into two.



chromosome (p. 239)
chromatin (p. 239)
cell cycle (p. 240)
interphase (p. 241)
mitosis (p. 241)
cytokinesis (p. 241)
chromatid (p. 242)
centromere (p. 242)

10.3 Regulating the Cell Cycle

- Internal and external regulatory proteins help control a cell's growth and division.
- Apoptosis removes old or unneeded cells from an organism.
- Cancer cells do not respond to the signals that tell most cells to stop growing.

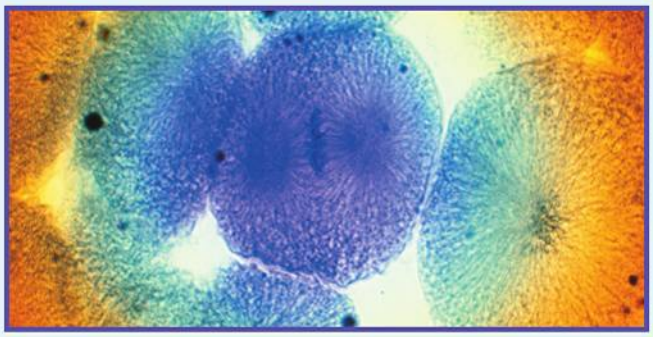
growth factors (p. 246)
apoptosis (p .246)
cancer (p. 247)

10.4 Cell Differentiation

- During the development of an organism, cells differentiate into many types of cells.
- Stem cells have the ability to differentiate into other types of cells.
- Stem cell research may offer many medical benefits, but it also raises ethical concerns.

embryo (p. 248)
differentiation (p. 248)
totipotent (p. 249)
pluripotent (p. 249)
stem cells (p. 249)
multipotent (p. 250)

10 CHECK Understanding



Assess the Big idea Growth, Development, and Reproduction

Write an answer to the question below.
Q: How does a cell produce a new cell?

Constructed Response

Write an answer to each of the numbered questions below. The answer to each question should be one or two paragraphs. To help you begin, read the **Hints** below the questions.

1. **How does cell growth affect the ability of a cell to exchange materials with its environment?**

   Hint The exchange of materials is important to cells. Materials must come into a cell. Materials must go out of a cell.

   Hint As a cell grows, the relationship of its surface area to its volume changes.

2. **What are the main events of interphase?**

   Hint There are the three phases that make up interphase. List the phases in the order that they happen.

   Hint Look at the diagram called Eukaryotic Cell Cycle.

3. **In the future, how might stem cells be important for dealing with human health problems?**

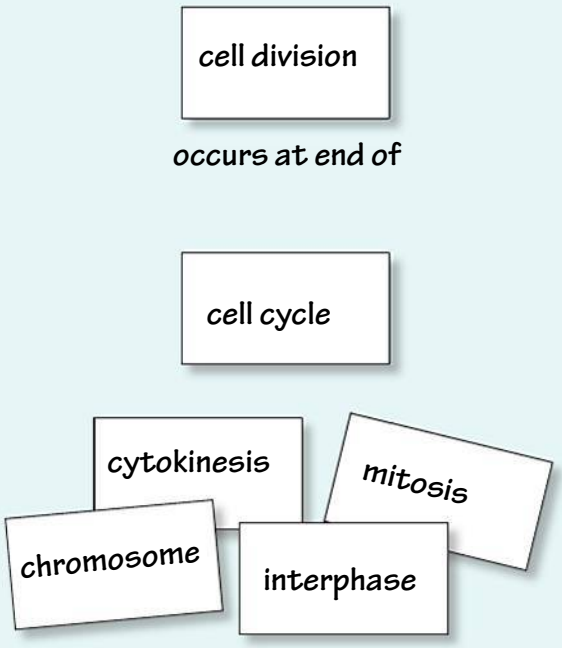
   Hint Stem cells do things that most other cells cannot do.

Foundations for Learning Wrap-Up

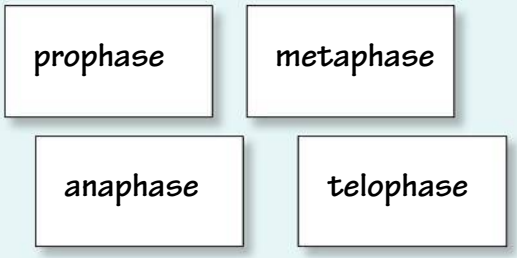
Use the index cards you prepared when you started the chapter as a tool to help you organize your thoughts about cell growth and division.

Activity 1 Working with a partner, choose five index cards at random. Explain how each word is related to the other. If the words are not related, explain why. Take turn choosing cards.

Activity 2 Working in a small group, choose a group of cards whose terms are related. Construct a concept map by placing the cards on a table and describing how the words are connected. Make sure you use each of the cards at least once.



You may want to add a card for each phase of mitosis.



10.1 Cell Growth, Division, and Reproduction

Understand Key Concepts

1. A cell is limited in size by access to the genetic information contained in its

a. cytoplasm.
b. cell membrane.
c. DNA.
d. organelles.

Test-Taking Tip

Anticipate the Answer Think of your own answer before looking at the answer choices. Select the answer choice that comes closest to your own answer. In question 1, answer **c** is correct because genetic information is contained in DNA. All the other answers refer to cell parts. They are intended to distract you from the right answer.

2. Which material is it important for a cell to remove?

a. water
b. waste
c. food
d. oxygen

3. Identify one way in which asexual and sexual reproduction are alike and one way in which they are different.

Think Critically

4. **Relate Cause and Effect** In a rapidly changing environment, which organisms have an advantage—those that reproduce asexually or those that reproduce sexually? Explain.

10.2 The Process of Cell Division

Understand Key Concepts

5. For a cell to divide successfully, it must first

a. form a new cell plate or cell membrane.
b. divide its cytoplasm and organelles.
c. increase its number of chromosomes.
d. copy its genetic information.

6. The cell cycle in a eukaryotic cell is divided into

a. prophase, anaphase, and telophase.
b. interphase, metaphase, and cytokinesis
c. interphase, mitosis, and cytokinesis.
d. interphase, anaphase, and telophase.

7. What happens to a chromosome during cell division?

8. Identify the four phases of mitosis and give a brief description of what happens in each phase.

Think Critically

9. **Compare and Contrast** How does cell division in prokaryotes differ from cell division in eukaryotes?

10.3 Regulating the Cell Cycle

Understand Key Concepts

10. The timing in the cell cycle in eukaryotic cells is believed to be controlled by a group of closely related proteins known as

a. chromatids.
b. cyclins.
c. centromeres.
d. centrioles.

11. What type of regulatory proteins are activated when you break a bone?

a. cyclins
b. internal regulators
c. bone cells
d. growth factors

12. What effect do cancer cells have on the healthy cells that surround them?

13. What role does apoptosis play in a tadpole whose tail shrinks as it develops into a frog?

Think Critically

14. **Compare and Contrast** How are cancer cells different from other cells? How are they alike?

10 CHECK Understanding

10.4 Cell Differentiation

Understand Key Concepts

15. Which type of cell can differentiate into any kind of cell?

a. totipotent **c.** multipotent
b. pluripotent **d.** differentiated

16. An organism at an early stage of development is

a. a stem cell. **c.** a cytokinesis.
b. a chromosome. **d.** an embryo.

17. What is cell differentiation? How is it important to an organism's development?

18. Describe how scientists may help ease the ethical concerns about stem cell research.

Think Critically

19. **Relate Cause and Effect** Suppose researchers discover how to make skin stem cells pluripotent. How might this affect treatments for heart attack patients?

Connecting Concepts

Use Science Graphics

Use the data table to answer the questions 20 and 21.

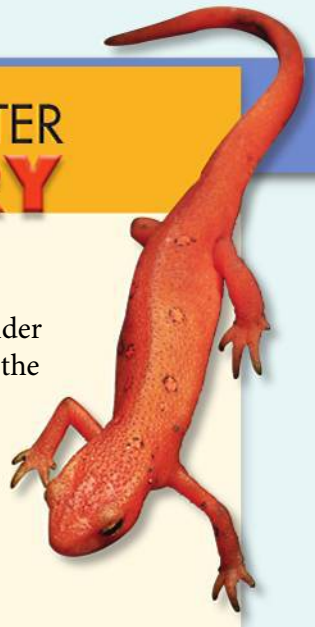
Life Spans of Various Human Cells

Cell Type	Life Span	Cell Division
Red blood cells	<120 days	Cannot divide
Cardiac (heart) muscle	Long-lived	Cannot divide
Smooth muscle	Long-lived	Can divide
Neuron (nerve cell)	Long-lived	Most do not divide

20. **Compare and Contrast** Where would you expect to find active stems cells, in the bone where blood cells are produced or in the heart? Explain your thinking.

21. **Infer** Suppose cancer cells were added to the table. What would probably be written in the "Cell Division" column? Explain.

solve the CHAPTER MYSTERY



PET SHOP ACCIDENT

Julia checked the hurt salamander each day. About a month after the accident, Julia realized that a new leg was going to replace the lost one! Salamanders are one of a few vertebrates that can regenerate, or grow, a complete limb.

Look at the pictures that show how a new leg develops. Then answer the questions.

Week 1: Dedifferentiation
Cells in the wounded area dedifferentiate. This means they are unable to differentiate. Cells can no longer perform their specialized jobs.

Week 3: Forming a web of cells
The dedifferentiated cells move to the wounded area. There they form a tangled web of growing, undifferentiated cells.

Week 5: Redifferentiation
The web of cells redifferentiate, again becoming differentiated. These new cells produce the new leg. The leg will continue to grow until it is full size.

1. **Relate Cause and Effect** Cells in the salamander's leg first had to dedifferentiate. Why was this a key part of growing a new leg?

2. **Classify** What type of stem cells do you think the tangled web of cells contain?

UntamedScience **Never Stop Exploring Your World.** Finding the solution to the pet shop mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Standardized Test Prep

Multiple Choice

1. Which statement is true regarding a cell's surface area-to-volume ratio?
- **A** As the size of a cell increases, its volume decreases.
- **B** As the size of a cell decreases, its volume increases.
- **C** Larger cells will have a greater surface area-to-volume ratio.
- **D** Smaller cells will have a greater surface area-to-volume ratio.

2. Which of the following is *not* an advantage of asexual reproduction?
- **A** simple and efficient
- **B** produces large number of offspring quickly
- **C** increases genetic diversity
- **D** requires one parent

3. At the beginning of cell division, a chromosome consists of two
- **A** centromeres.
- **B** centrioles.
- **C** chromatids.
- **D** spindles.

4. What regulates the timing of the cell cycle in eukaryotes?
- **A** chromosomes
- **B** cyclins
- **C** nutrients
- **D** DNA and RNA

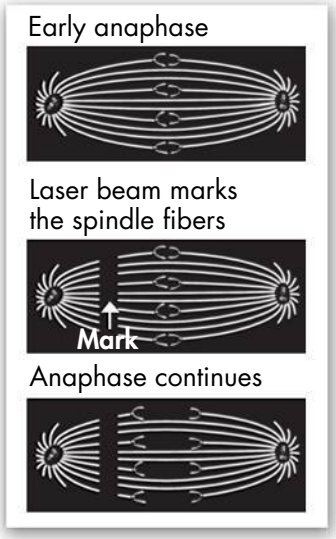
5. The period between cell divisions is called
- **A** interphase.
- **B** prophase.
- **C** G_3 phase.
- **D** cytokinesis.

6. Which of the following is true about totipotent cells?
- **A** Totipotent cells develop in the inner cell mass.
- **B** Totipotent cells are differentiated cells.
- **C** Totipotent cells can differentiate into any type of cell and tissue.
- **D** Adult stem cells are totipotent cells.

7. A cell enters anaphase before all of its chromosomes have attached to the spindle. This may indicate that the cell is not responding to
- **A** internal regulators.
- **B** cyclins.
- **C** growth factors.
- **D** apoptosis.

Questions 8–10

The spindle fibers of a dividing cell were labeled with a fluorescent dye. At the beginning of anaphase, a laser beam was used to stop the dye from glowing on one side of the cell, thereby marking the fibers, as shown in the second diagram. The laser did not inhibit the normal function of the fibers.



8. This experiment tests a hypothesis about
- **A** how chromosomes migrate during cell division.
- **B** how fluorescent dyes work in the cell.
- **C** the effect of lasers on cells.
- **D** why cells divide.

9. The diagram shows that the spindle fibers
- **A** shorten on the chromosome side of the mark.
- **B** lengthen on the chromosome side of the mark.
- **C** shorten on the centriole side of the mark.
- **D** lengthen on the centriole side of the mark.

10. A valid conclusion that can be drawn from this experiment is that the spindle fibers break down
- **A** at the centrioles.
- **B** in the presence of dye.
- **C** when marked by lasers.
- **D** when they are attached by chromosomes.

Open-Ended Response

11. Explain why careful regulation of the cell cycle is important to multicellular organisms.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10	11
See Lesson	10.1	10.1	10.2	10.3	10.2	10.4	10.3	10.2	10.2	10.2	10.3

UNIT 3 Cells

Unit Project

Superhero Cell

Do you like reading comics? Have you ever designed a comic book of your own? Here's your chance! A high school teacher has contacted you asking for a comic book on cells and cell processes. She has told you that her students are just about to start studying cells and need a good introduction to the topic. You've been tasked with developing the story line and visuals that will provide the students with a basic understanding of cell structure and function. Remember that sometimes a picture can be worth a thousand words—so be creative!

Your Task Write a comic book about a "superhero cell" for an audience of high school students.

Be sure to

- incorporate important concepts and details about the structure and function of various organelles and cell processes.
- provide insight into the ways cells work and interact with their environment.
- be entertaining and creative.

Reflection Questions

1. **Score your project using the rubric below. What score did you give yourself?**
2. **What did you do well on this project?**
3. **What about your project needs improvement?**
4. **Exchange your comic book with a classmate and have him/her read it. What did your partner like about your comic book? What did he/she think could use improvement?**

Assessment Rubric

Score	Scientific Content	Quality of Comic Book
4	The comic book includes accurate details about the structures and functions of several organelles and cell processes. It provides exceptional insight into how a cell works and interacts with its environment.	The comic book is thoughtfully and creatively written and illustrated.
3	The comic book includes mostly accurate details about the structure and functions of organelles and cell processes. It provides good insight into how a cell works and interacts with its environment.	The comic book is well written and includes some creativity. Illustrations are clear.
2	The comic book includes a few details about the structure and functions of organelles and cell processes, with some inaccuracies. It provides some insight into how a cell works and interacts with its environment.	The comic book needs some edits and could use more creativity. Some parts of the story line and illustrations are difficult to follow.
1	The comic book includes vague and inaccurate information about the structure and functions of organelles and cell processes. It provides little insight into how a cell works and interacts with its environment.	The comic book needs significant edits and includes very little creativity. Story line and illustrations are unclear.