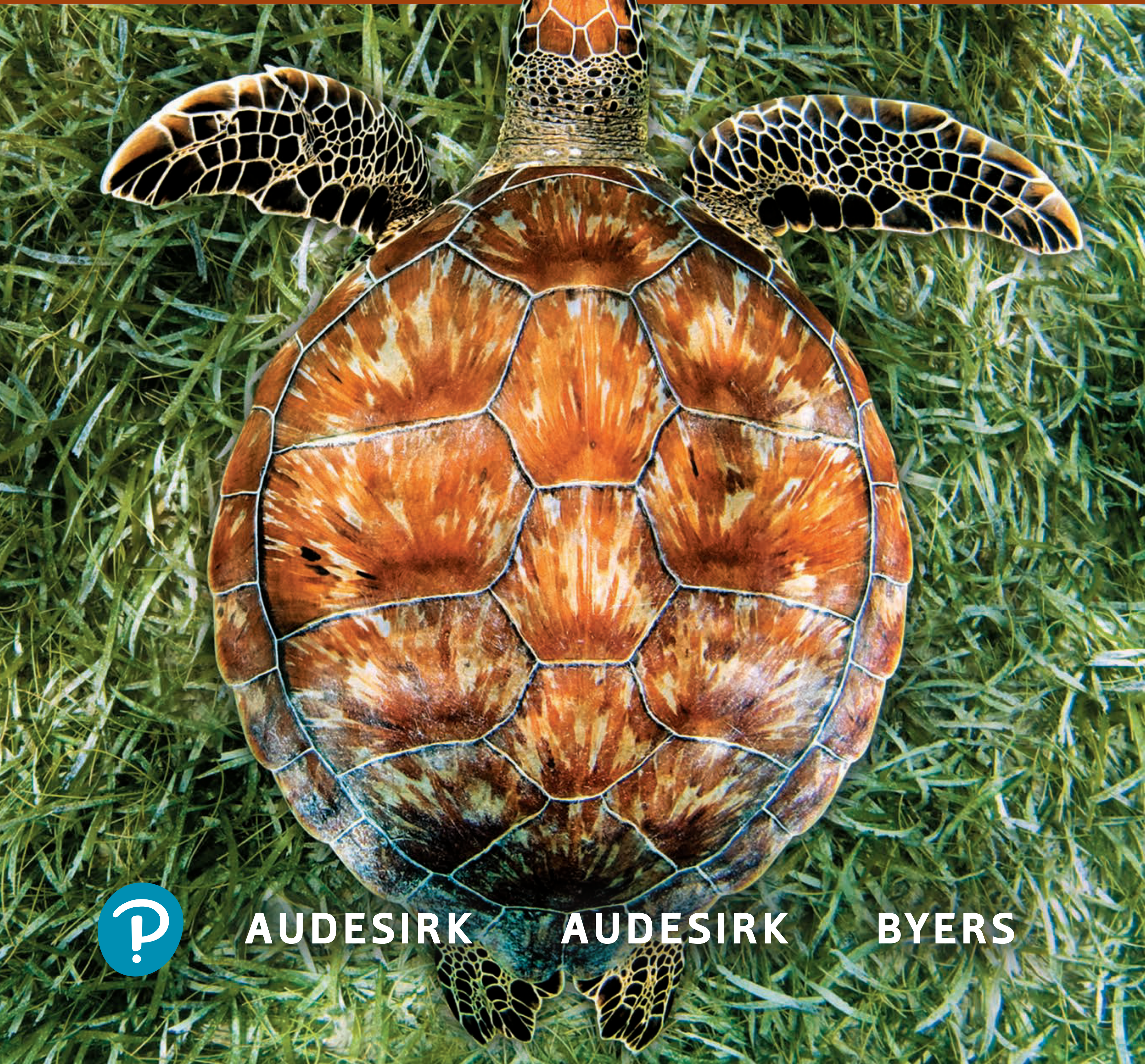
BIOLOGY

LIFE ON EARTH

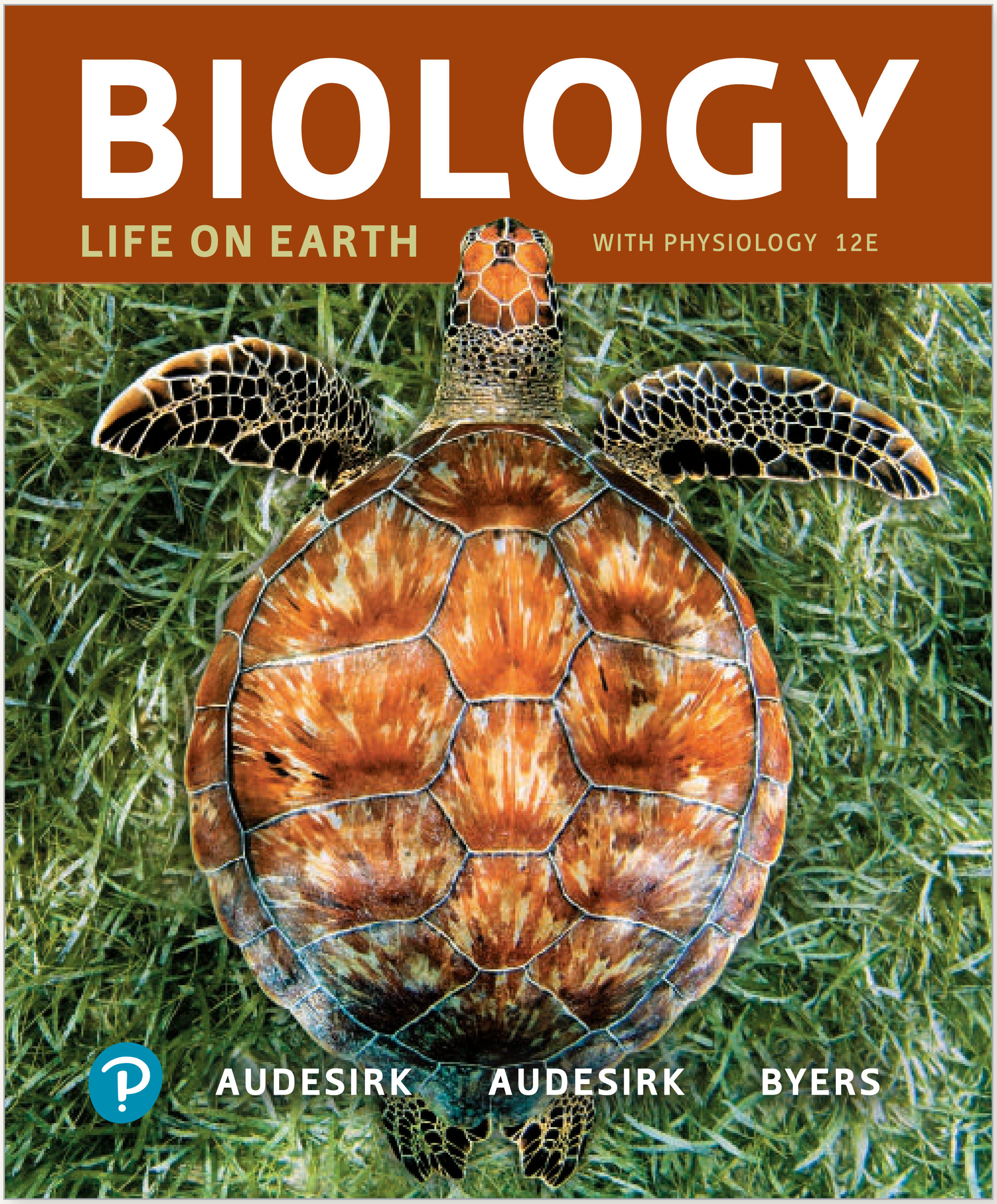
TWELFTH EDITION



AUDESIRK AUDESIRK BYERS

The most comprehensive coverage at the most affordable price

Biology: Life on Earth fosters discovery and scientific understanding that students can use throughout their lives. Engaging Case Studies and thoughtful pedagogy help students develop critical thinking and scientific literacy skills. This loose-leaf edition expands its focus on the process of science while maintaining its conversational, question-and-answer presentation style that has made it a best-seller.



Pearson

Engage students with course material that relates to their lives

Each chapter presents a Case Study that describes a true and relevant event or phenomenon and ties the related biological concepts to the real world. Probing questions at the end of the chapter encourage students to further reflect on the Case Study take-home lessons. Updates to the 12th edition include a new Case Study on bioengineering human organs.

4

Cell Structure and Function

An artificial bladder, ready to be transplanted.

CASE STUDY

New Parts for Human Bodies

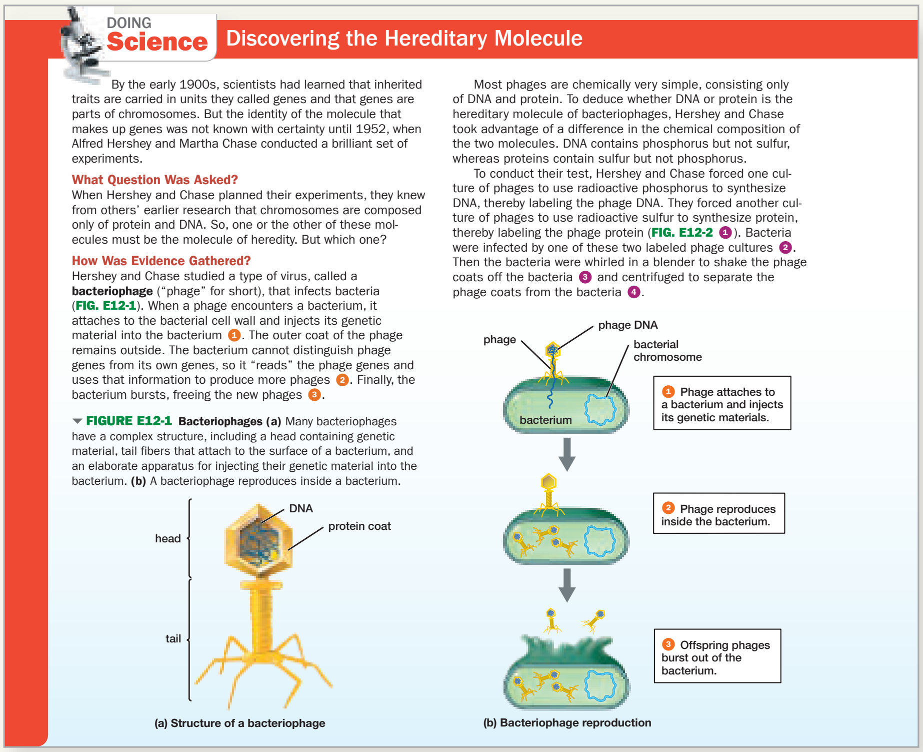
WHEN LUKE MASSELLA WAS 10 YEARS OLD, he faced a very serious health crisis. Complications from a birth defect had left Luke with a bladder that could not fully function, and his dysfunctional bladder was inflicting damage on his kidneys. Without some kind of intervention, Luke's kidneys would fail, with potentially fatal consequences. With Luke's health declining rapidly, he underwent an experimental surgery in which his bladder was replaced with a new one. But the new bladder was not a natural organ taken from a cadaver. Instead, Luke's new bladder was grown in a laboratory, bioengineered just for him.

Luke's bioengineered bladder was built from his own cells. A team led by Dr. Anthony Atala removed a very small piece of tissue from Luke's urinary tract. The scientists induced the cells to multiply and then spread the resulting cells over a biodegradable, bladder-shaped mold made largely of the protein collagen. With a thin layer of muscle cells on the outside, and a thin layer of epithelial cells on the inside, the mold was placed in a nutrient broth inside a temperature-controlled "bioreactor," where further cell proliferation ultimately formed a complete bladder. When the artificial bladder was ready, surgeons used it to replace Luke's damaged organ.

In the years after his pioneering surgery, Luke went on to become the captain of his high school wrestling team, graduate from college, and begin his career. Meanwhile, Dr. Atala and his team, along with scientists in numerous other labs around the world, have made further progress toward the goal of producing bioengineered tissues and organs to help people who need theirs repaired or replaced.

Bioengineering human organs demonstrates our expanding ability to manipulate cells, the fundamental units of life. What structures make up cells? What new bioengineering techniques involving human or animal cells are being developed and tested?

Develop scientific literacy skills



DOING **Science** Discovering the Hereditary Molecule

By the early 1900s, scientists had learned that inherited traits are carried in units they called genes and that genes are parts of chromosomes. But the identity of the molecule that makes up genes was not known with certainty until 1952, when Alfred Hershey and Martha Chase conducted a brilliant set of experiments.

What Question Was Asked?
When Hershey and Chase planned their experiments, they knew from others' earlier research that chromosomes are composed only of protein and DNA. So, one or the other of these molecules must be the molecule of heredity. But which one?

How Was Evidence Gathered?
Hershey and Chase studied a type of virus, called a **bacteriophage** ("phage" for short), that infects bacteria (**FIG. E12-1**). When a phage encounters a bacterium, it attaches to the bacterial cell wall and injects its genetic material into the bacterium 1. The outer coat of the phage remains outside. The bacterium cannot distinguish phage genes from its own genes, so it "reads" the phage genes and uses that information to produce more phages 2. Finally, the bacterium bursts, freeing the new phages 3.

FIGURE E12-1 **Bacteriophages (a)** Many bacteriophages have a complex structure, including a head containing genetic material, tail fibers that attach to the surface of a bacterium, and an elaborate apparatus for injecting their genetic material into the bacterium. **(b)** A bacteriophage reproduces inside a bacterium.

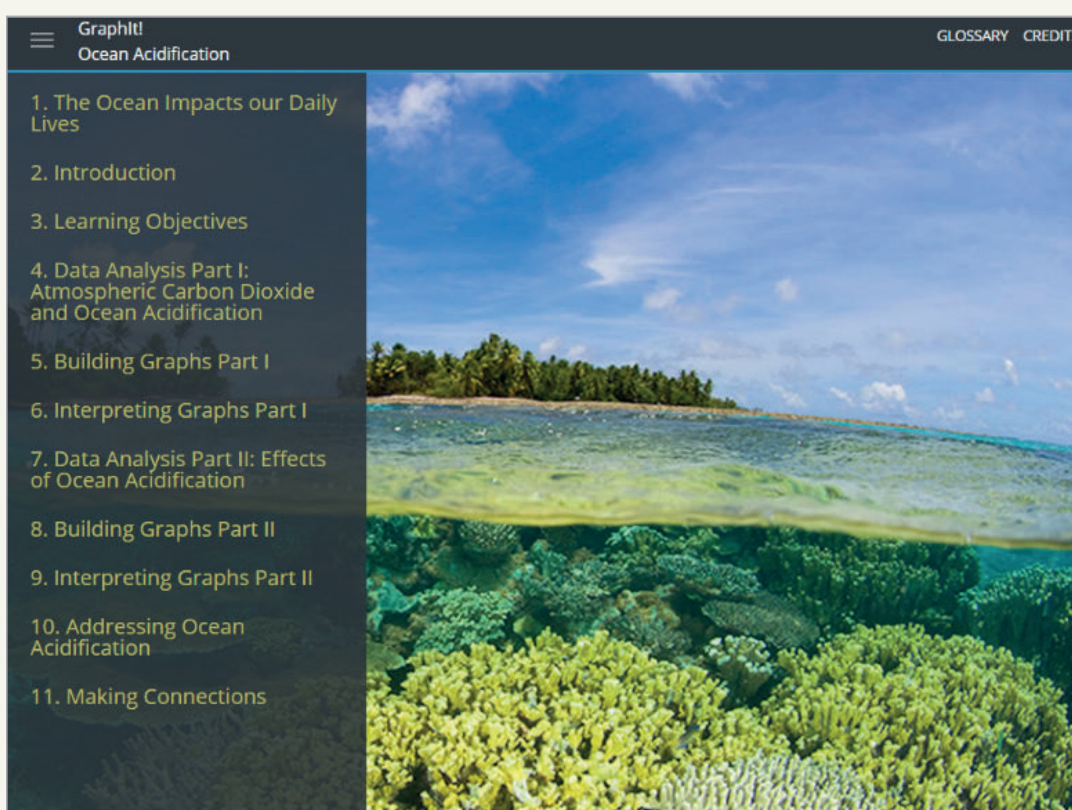
Most phages are chemically very simple, consisting only of DNA and protein. To deduce whether DNA or protein is the hereditary molecule of bacteriophages, Hershey and Chase took advantage of a difference in the chemical composition of the two molecules. DNA contains phosphorus but not sulfur, whereas proteins contain sulfur but not phosphorus.

To conduct their test, Hershey and Chase forced one culture of phages to use radioactive phosphorus to synthesize DNA, thereby labeling the phage DNA. They forced another culture of phages to use radioactive sulfur to synthesize protein, thereby labeling the phage protein (**FIG. E12-2** 1). Bacteria were infected by one of these two labeled phage cultures 2. Then the bacteria were whirled in a blender to shake the phage coats off the bacteria 3 and centrifuged to separate the phage coats from the bacteria 4.

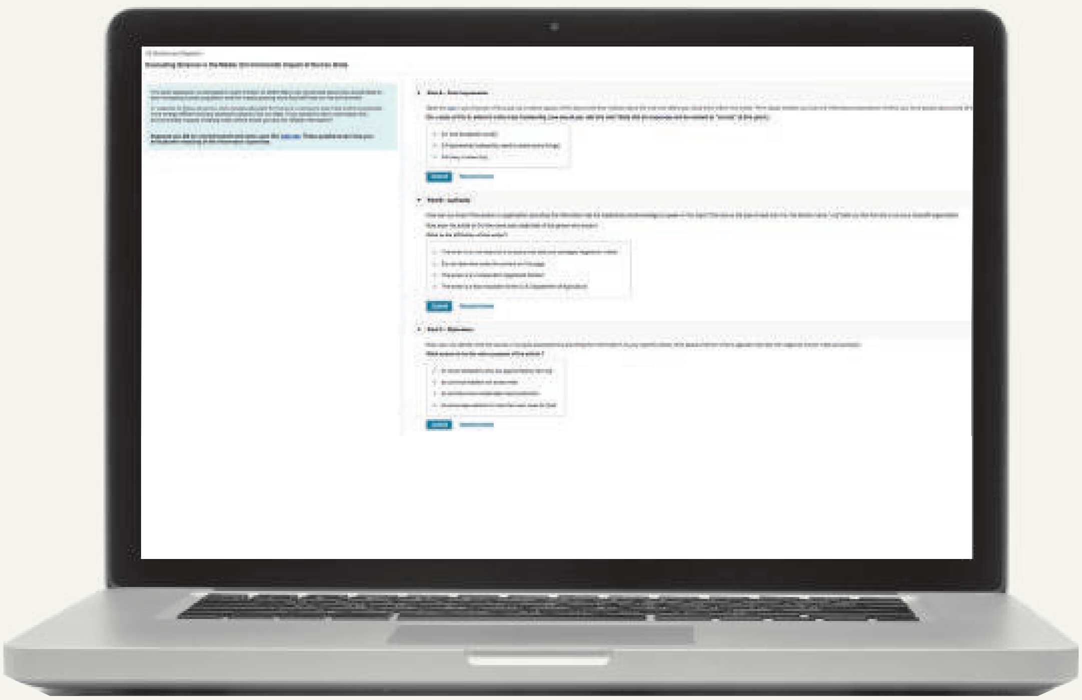
P. 180

NEW! Doing Science boxes explore the process of scientific discovery, experimental design, and exciting new biotechnology techniques, helping students understand how the process of science plays out in a multitude of different ways. Topics include Using Brain Imaging to Diagnose Disease (pg. 22), Demonstrating that DNA is the Genetic Molecule (pg. 180), Radiometric Dating (pg. 287), and Forest Fragmentation (p. 545).

NEW! GraphIt! Coaching Activities help students read, interpret, and create graphs that explore real environmental issues using real data. All 10 activities explore current topics such as the carbon footprint of food, fresh water availability, and ocean acidification in an entirely new mobile experience with accessible design.

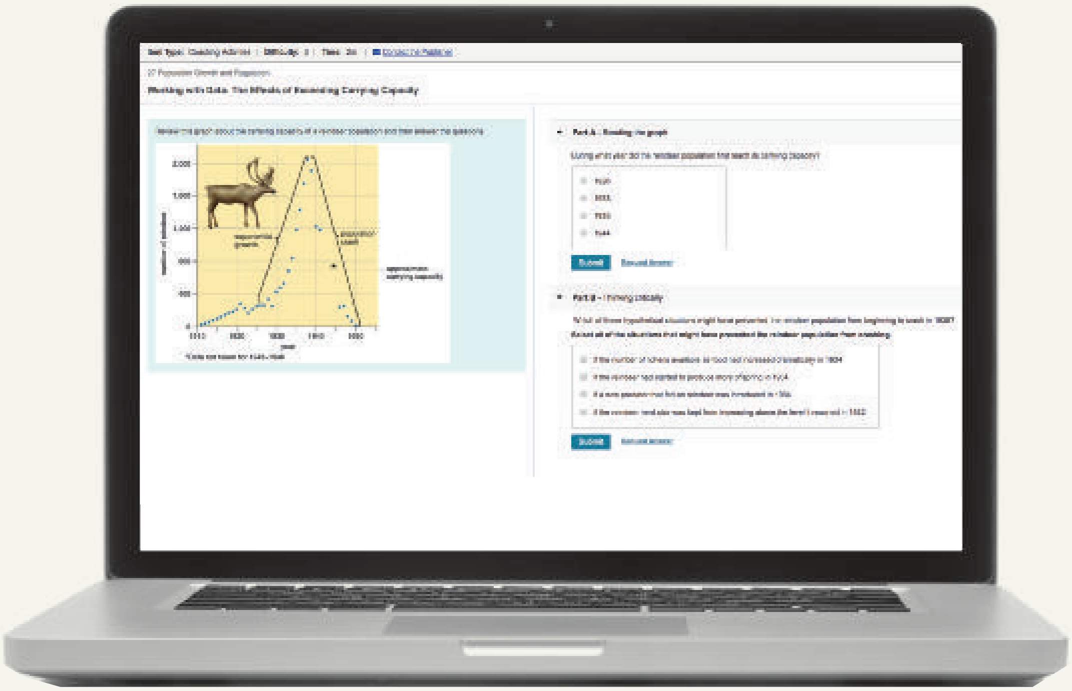


Deliver trusted content . . .

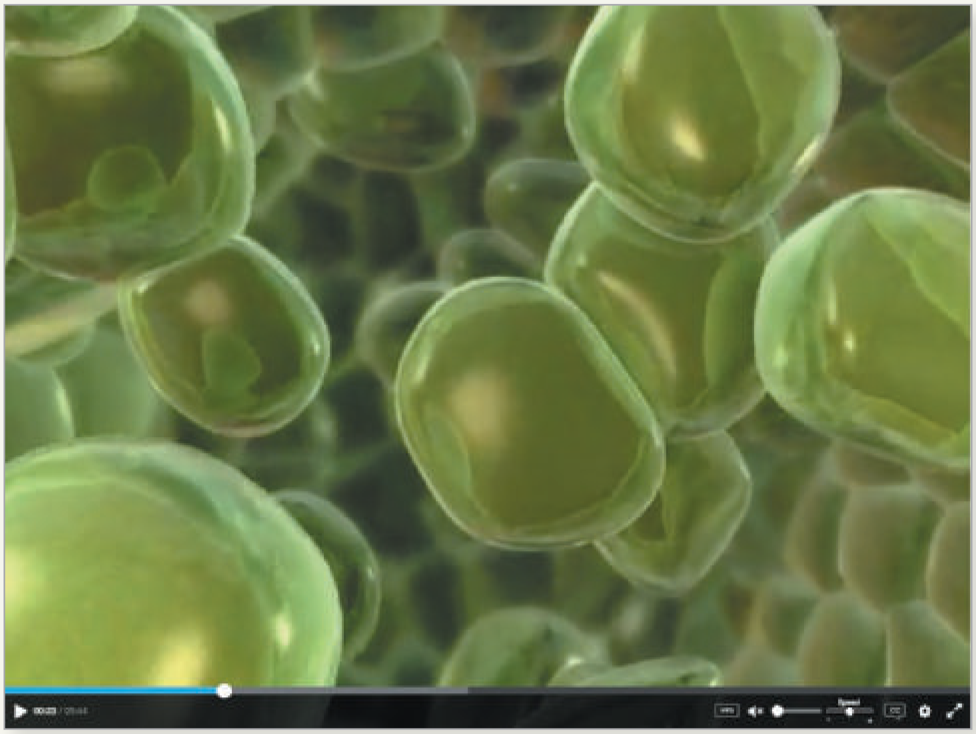


Evaluating Science in the Media coaching activities guide students through a step-by-step process for evaluating the authority, motivation, and reliability of online sources of scientific information. Topics include genetically modified organisms, head injuries, tanning and skin cancer, and more.

Working with Data activities ask students to analyze and apply their knowledge of biology to a graph or a set of data from the text.



with Mastering Biology



BioFlix™ 3D movie-quality animations help your students visualize complex biology topics and include automatically-graded coaching activities with personalized feedback and hints.

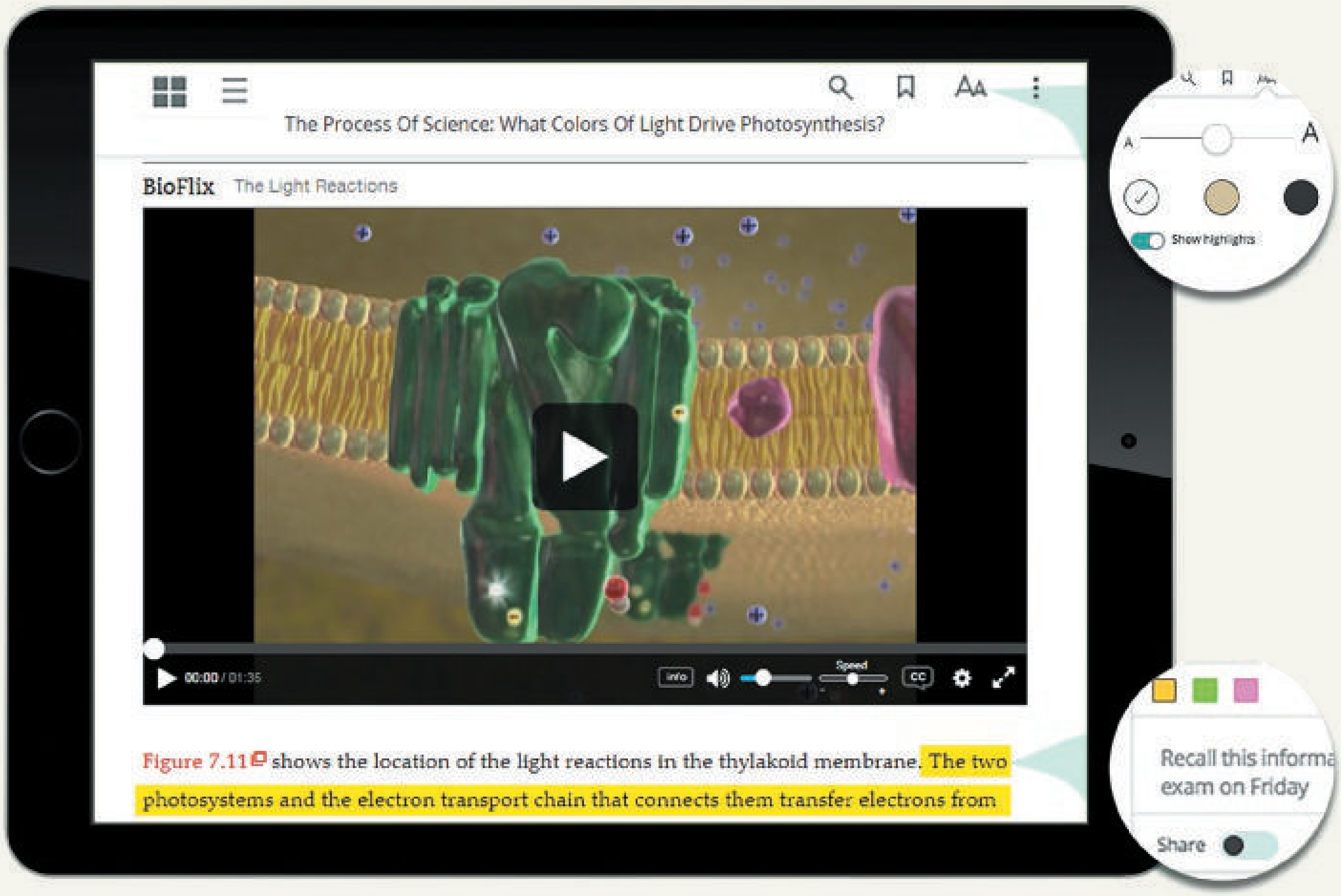
Everyday Biology Videos briefly explore interesting and relevant biology topics that relate to concepts that students are learning in class. These 20 videos, produced by the BBC, can be assigned in Mastering Biology with assessment questions.

Give students anytime, anywhere access with Pearson eText

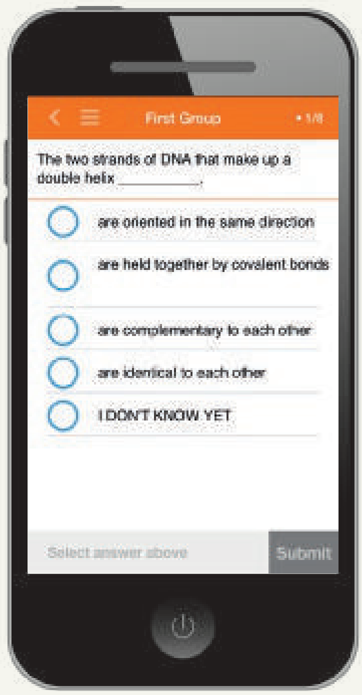
Pearson eText is a simple-to-use, mobile-optimized, personalized reading experience available within Mastering. It allows students to easily highlight, take notes, and review key vocabulary all in one place—even when offline. Seamlessly integrated videos and other rich media engage students and give them access to the help they need, when they need it. Pearson eText is available within Mastering when packaged with a new book; students can also purchase Mastering with Pearson eText online.

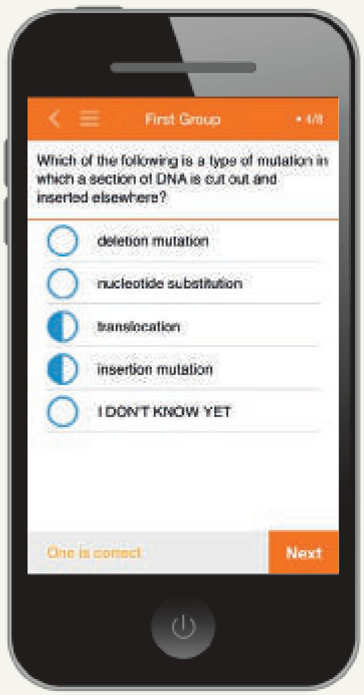
For instructors not using Mastering, Pearson eText can also be adopted on its own as the main course material.

NEW! BioFlix animations are now embedded in the eText, giving students immediate access to engaging, accurate, and reliable videos, right when they need them most.



Improve learning with Dynamic Study Modules



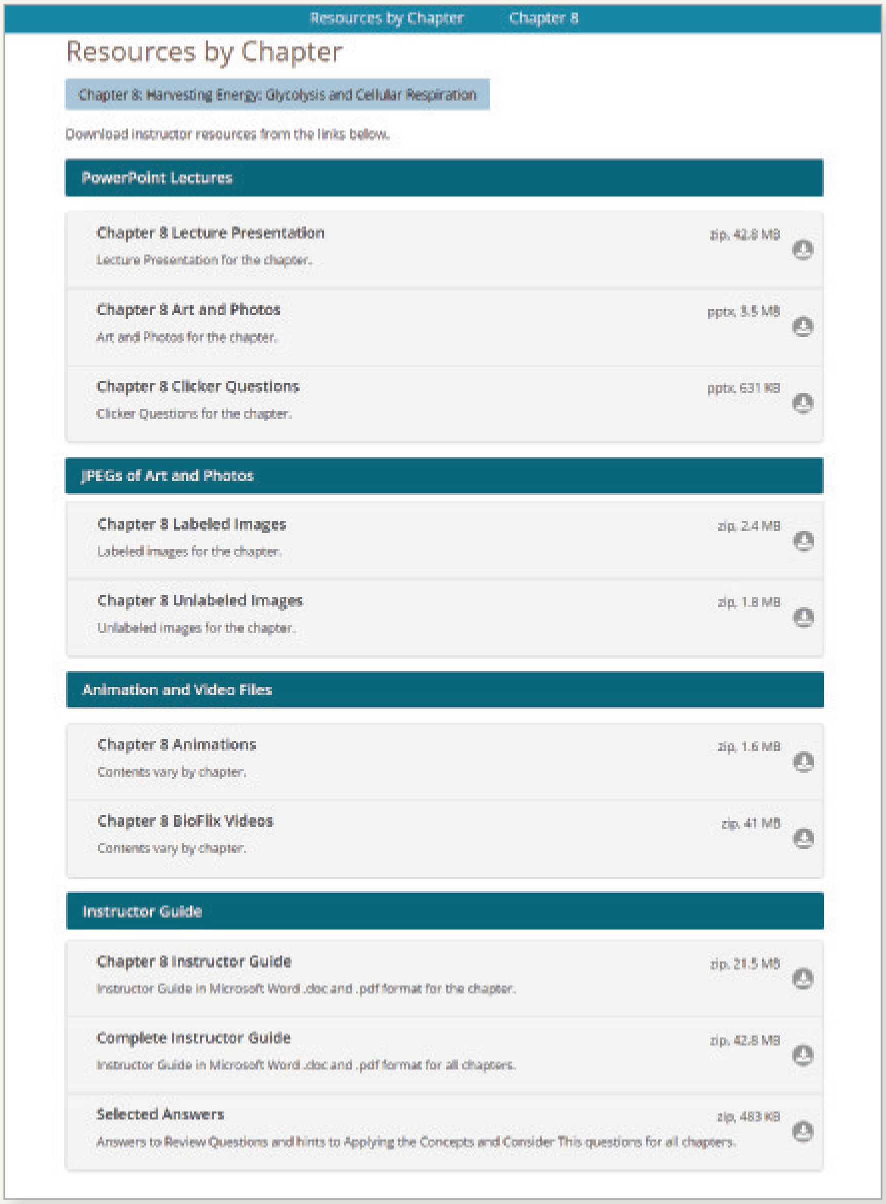


Dynamic Study Modules in Mastering Biology help students study effectively—and at their own pace—by keeping them motivated and engaged. The assignable modules rely on the latest research in cognitive science, using methods—such as adaptivity, gamification, and intermittent rewards—to stimulate learning and improve retention.

Each module poses a series of questions about a course topic. These question sets adapt to each student's performance and offer personalized, targeted feedback to help them master key concepts. With **Dynamic Study Modules,** students build the confidence they need to deepen their understanding, participate meaningfully, and perform better—in and out of class.

Instructor support you can rely on

Biology: Life on Earth **includes a full suite of instructor support materials in the Instructor Resources area in Mastering Biology. Resources include an updated Instructor Guide, with new topics to help launch classroom discussions; animations, videos, and lecture presentations to show in class; and free access to our unique Instructor Exchange website, where you can share ideas with other non-majors biology faculty.**



BIOLOGY

LIFE ON EARTH

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BIOLOGY

LIFE ON EARTH

TWELFTH EDITION

TERESA AUDESIRK
UNIVERSITY OF COLORADO DENVER

GERALD AUDESIRK
UNIVERSITY OF COLORADO DENVER

BRUCE E. BYERS
UNIVERSITY OF MASSACHUSETTS AMHERST

Pearson

Courseware Portfolio Manager: Cady Owens
Director of Portfolio Management: Beth Wilbur
Content Producer: Anastasia Slesareva
Managing Producer: Michael Early
Courseware Director, Content Development: Ginnie Simione Jutson
Senior Development Editor: Jennifer Angel
Courseware Editorial Assistant: Chelsea Noack
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About the Authors

TERRY AND GERRY AUDESIRK grew up in New Jersey, where they met as undergraduates, Gerry at Rutgers University and Terry at Bucknell University. After marrying in 1970, they moved to California, where Terry earned her doctorate in marine ecology at the University of Southern California and Gerry earned his doctorate in neurobiology at the California Institute of Technology. As postdoctoral students at the University of Washington's marine laboratories, they worked together on the neural bases of behavior, using a marine mollusk as a model system.

They are now emeritus professors of biology at the University of Colorado Denver, where they taught introductory biology and neurobiology from 1982 through 2006. In their research, funded primarily by the National Institutes of Health, they investigated the mechanisms by which neurons are harmed by low levels of environmental pollutants and protected by estrogen.

Terry and Gerry are long-time members of many conservation organizations and share a deep appreciation of nature and of the outdoors. They enjoy hiking in the Rockies, walking and horseback riding near their home outside Steamboat Springs, and singing in the community chorus. Keeping up with the amazing and endless stream of new discoveries in biology provides them with a continuing source of fascination and stimulation. They are delighted that their daughter Heather has become a teacher and is inspiring a new generation of students with her love of chemistry.

BRUCE E. BYERS is a Midwesterner transplanted to the hills of western Massachusetts, where he is a professor in the biology department at the University of Massachusetts Amherst. He has been a member of the faculty at UMass (where he also completed his doctoral degree) since 1993. Bruce teaches courses in evolution, ornithology, and animal behavior, and does research on the function and evolution of bird vocalizations.

With love to Jack, Lori, and Heather and in loving memory of Eve and Joe.

— T. A. & G. A.

In memory of Bob Byers, a biologist at heart.

— B. E. B.

ABOUT THE COVER A green sea turtle (***Chelonia mydas***) swims above a bed of seagrass in the Caribbean Sea. Green sea turtles are found in tropical and subtropical marine waters worldwide, where adults feed mainly on algae and marine plants. Immature green sea turtles have a more omnivorous diet, consuming mollusks, jellyfish, and other invertebrates. Like other sea turtle species, green sea turtles migrate long distances from their feeding areas to their mating areas. After mating, a female emerges from the water onto a sandy beach, where she buries her eggs. A couple of months later, the eggs hatch and the hatchling turtles make their way back to the sea. The International Union for Conservation of Nature classifies green sea turtles as endangered. Many turtles drown when they become entangled in fishing nets, and people in many places harvest sea turtles and their eggs for food. Housing developments on sea turtle nesting beaches pose an additional threat.

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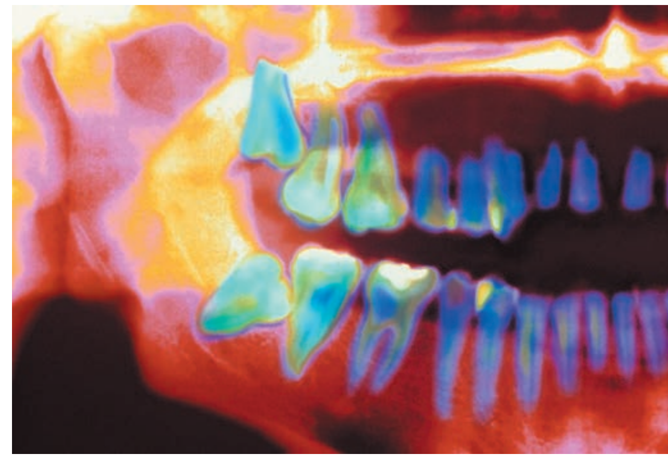
Case Studies



Essays

Earth Watch

Health Watch

Doing Science

Have You Ever Wondered . . .

Preface

THE CASE FOR SCIENTIFIC LITERACY

Climate change, biofuels versus food and forests, bioengineering, stem cells in medicine, potential flu pandemics, the plight of polar bears and pandas, human population growth and sustainability: these are just some of the very real, urgent, and interrelated concerns facing our increasingly connected human societies. The Internet places a wealth of information—and a flood of misinformation—at our fingertips. Never have scientifically literate students been more important to humanity's future. As educators, we feel humbled before this massive challenge. As authors, we feel hopeful that the Twelfth Edition of *Biology: Life on Earth* will help lead introductory biology students along paths to understanding.

Scientific literacy requires a foundation of factual knowledge that provides a solid and accurate cognitive framework into which new information can be integrated. But more importantly, it endows people with the mental tools to separate the wealth of data from the morass of misinformation. Scientifically literate citizens are better able to evaluate facts and make informed choices in their personal lives and in the political arena.

This Twelfth Edition of *Biology: Life on Earth* continues our tradition of:

- Helping instructors present biological information in a way that will foster scientific literacy among their students.
- Helping to inspire students with a sense of wonder about the natural world, fostering an attitude of inquiry and a keen appreciation for knowledge gained through science.
- Helping students to recognize the importance of what they are learning to their future roles in our rapidly changing world.

BIOLOGY: LIFE ON EARTH, TWELFTH EDITION

. . . Is Organized Clearly and Uniformly

Navigational aids help students explore each chapter. An important goal of this organization is to present biology as a hierarchy of closely interrelated concepts rather than as a compendium of independent topics.

- Major sections are introduced as broad questions that stimulate students to think about the material to follow; subheadings are statements that summarize their specific content.
- Each major section concludes with "Check Your Learning" questions that remind students of the key concepts and content in the preceding passage.
- "Case Study Continued" segments end with probing questions to help students anticipate what they will learn next.
- A "Summary of Key Concepts" section ends each chapter, providing a concise, efficient review of the chapter's major topics.

. . . Engages and Motivates Students

Scientific literacy cannot be imposed on students—they must actively participate in acquiring the necessary information and skills. To be inspired to accomplish this, they must first recognize that biology is about their own lives. For example, we help students acquire a basic understanding and appreciation of how their own bodies function by including information about diet and weight, cancer, and lower back pain.

We fervently hope that students who use this text will come to see their world through keener eyes. For example, they will perceive forests, fields, and ponds as vibrant and interconnected ecosystems brimming with diverse life-forms rather than as mundane features of their everyday surroundings. If we have done our job, students will also gain the interest, insight, and information they need to look at how humanity has intervened in the natural world. If they ask the question, "Is this activity sustainable?" and then use their new knowledge and critical thinking skills to seek some answers, we can be optimistic about the future.

In support of these goals, the Twelfth Edition has updated features that make Biology more engaging and accessible.

- **Case Studies** Each chapter opens with an attention-grabbing "Case Study" that highlights topics of emerging relevance in today's world. Case Studies, including "Unstable Atoms Unleashed" (Chapter 2), "New Parts for Human Bodies" (Chapter 4), and "Unwelcome Dinner Guests" (Chapter 20), are based on news events, personal interest stories, or particularly fascinating biological topics. "Case Study Continued" segments weave the topic throughout the chapter, and "Case Study Revisited" completes the chapter, exploring the topic further in light of the chapter's lessons.
- **Boxed Essays** Three categories of essays enliven the text. "Earth Watch" essays explore pressing environmental issues; "Health Watch" essays cover important or intriguing medical topics; and "Doing Science" essays explain how scientific knowledge is acquired. In addition, "In Greater Depth" essays that provide more detailed information on some topics are available on Mastering Biology.
- **"Have You Ever Wondered" Questions** These popular features demystify common and intriguing questions, showing biology in the real world.

- **End-of-Chapter Questions** The questions that conclude each chapter allow students to review the material in different formats—multiple choice, fill-in-the-blank, short-answer, and essay—that help them to study and assess what they have learned. Answers to the multiple choice, fill-in-the-blank, and short-answer questions are included in the back of the book. Hints for the essay questions are included on Mastering Biology.
- **Key Terms and a Complete Glossary** Boldfaced key terms are defined clearly within the text as they are introduced. These terms are also available on Mastering Biology as flashcards, providing students with an opportunity to quiz themselves on important definitions. The glossary, carefully written by the authors, provides complete definitions for all key terms, as well as for other important biological terms.

. . . Encourages Critical Thinking

Throughout the text, we aim to help students develop and improve their ability to think critically about scientific information and concepts. Aspects of the text that foster critical thinking include:

- **Two Question Types in Essays and Figure Captions** In each chapter, students encounter a number of questions designed to encourage them to think critically about the content. “Think Critically” questions focus on solving problems, thinking about scientific data, or evaluating a hypothesis. “Consider This” questions invite students to form an opinion or pose an argument for or against an issue, based on valid scientific information. Answers to “Think Critically” questions are included in the back of the book; hints for “Consider This” questions are included on Mastering Biology.
- **In-depth Questions for Classroom Discussion** A number of new “Think Deeper” questions, available in the Instructor Resource area, follow up and extend “Think Critically” questions by asking additional, related questions that require more extensive thought and analysis.
- **Chapter-Ending Thought Questions** The end-of-chapter material for each chapter concludes with “Applying the Concepts” questions that challenge students to apply knowledge gained in the chapter to novel problems.
- **“Doing Science” Essays** These essays illustrate the process of science in a methodical way, emphasizing the process of what scientists do. Essays describe the details of experiments, highlighting exciting technology and data. They are structured to emphasize the process of inquiry, with sections titled “What Question Was Asked?”, “How Was Evidence Gathered?”, and “What Was Learned?” All “Doing Science” essays conclude with a “Think Critically” or “Consider This” question, encouraging students to analyze data or engage with the topics presented in the essay.
- **Data in “Earth Watch” Essays** Students will find examples of real scientific data in the form of graphs and tables. The essays are accompanied by “Think Critically” questions that challenge students to interpret the data, fostering increased understanding of how science is communicated.

. . . Is a Comprehensive Learning Package

The Twelfth Edition of *Biology: Life on Earth* is a complete learning package, providing updated and innovative teaching aids for instructors and learning aids for students.

ACKNOWLEDGMENTS

Biology: Life on Earth enters its Twelfth Edition guided by the excellent team at Pearson. Beth Wilbur, Director of Portfolio Management, continues to oversee the enterprise with warmth, competence, and first-rate leadership. Courseware Portfolio Manager Cady Owens, Content Development Director Ginnie Simione Jutson, and Content Producer Anastasia Slesareva coordinated this complex and multifaceted endeavor. Ginnie and Cady did a wonderful job of working with us to develop a revision plan to further extend the text’s appeal and reach. We also appreciate Cady’s extensive travel to share her enthusiasm for the text and its extensive ancillary resources with educators across the country. Mary Tindle, Content Producer at SPi Global, did a marvelous job of keeping everything on track and on schedule. Senior Development Editor Jennifer Angel carefully reviewed every word and figure in the manuscript, making sure the prose was clear, the images informative, and the organization logical. In addition, Jennifer worked diligently and with ingenuity to ensure that page layouts were attractive and effective. We very much appreciate her attention to detail and thoughtful suggestions. Our outstanding copyeditor, Lucy Mullins, improved the text and art and caught errors that we had overlooked. The book boasts a large number of excellent new photos, tracked down with skill and persistence by Kristin Piljay. Matthew Perry made sure we had proper permission to use the photos we chose.

We are grateful to Imagineeringart.com, Inc., under the direction of Project Manager Stephanie Marquez, for deciphering our art instructions and patiently making new adjustments to already outstanding figures. We owe our beautifully redesigned text and delightful new cover to Jeff Puda and Design Manager Mark Ong.

We thank Allison Rona, Director of Product Marketing, for making sure the finished product reached your desk. In her role as Manufacturing Buyer, Stacey Weinberger’s expertise has served us well. The ancillaries are an endeavor fully as important as the text itself. Thanks also to Robert Johnson and Ashley Gordon for developing the outstanding Mastering Biology Web site that accompanies this text.

We are extremely fortunate to be working with the Pearson team. This Twelfth Edition of *Biology: Life on Earth* reflects their exceptional abilities and dedication.

Finally, we appreciate the 400+ faculty members from around the country who have checked and rechecked the text for accuracy and clarity over the past several years. Reviewers specific to the past two editions are listed below.

With gratitude,

TERRY AUDESIRK, GERRY AUDESIRK, AND BRUCE BYERS

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Western Oregon University
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Lake Michigan College
Min Zhong
Auburn University
Deborah Zies
University of Mary Washington

1 An Introduction to Life on Earth

A researcher in West Africa captures a bat that will be tested for Ebola virus.

CASE STUDY

The Boundaries of Life

IN LATE 2013, two-year-old Emile Ouamouno became the first victim of a disease outbreak that would ultimately kill thousands. Emile lived in a small village in the country of Guinea, West Africa, where he became infected with the Ebola virus, most likely through contact with bats that roosted in a huge, hollow tree near the village. The infection soon killed Emile. Within weeks of his death, Emile's mother, sister, and grandmother had also died of Ebola. Other villagers who caught the disease from Emile and his family carried the virus to nearby settlements before they, too, died. Thus began a chain of Ebola virus transmission that eventually sickened more than 28,000 people, killing 11,300 of them by the time the epidemic subsided in mid-2016.

Victims of Ebola experience symptoms that include fever, headache, joint and muscle aches, and stomach pains, followed by vomiting, bloody diarrhea, and organ failure. Internal hemorrhaging can leave victims bleeding from nearly every orifice. Death usually occurs within 7 to 16 days after the onset of symptoms. Ebola is transmitted by contact with the body fluids of infected individuals, so caregivers and undertakers wear "moon suits" to protect themselves. There is no cure for Ebola. However, the recent epidemic spurred a successful effort to develop an effective vaccine, raising the hope that future Ebola outbreaks can be prevented.

Ebola is one of many diseases caused by viruses. Although some viral diseases, such as smallpox and polio, have been largely eradicated, others, like the common cold and influenza (flu), continue to make us miserable. Perhaps most alarming are dangerous viral diseases that seem to emerge suddenly. AIDS was unknown until 1981, Ebola emerged in 1975, and Marburg virus disease appeared for the first time in 1967. New variants of the flu virus emerge regularly; some of these previously unknown variants have sparked deadly epidemics.

Although the viruses that infect humans are of special interest to us, viruses also infect every other form of life. Viruses have some things in common with the organisms they infect; for example, they reproduce and they evolve. But despite these lifelike qualities, scientists disagree about whether viruses are living organisms. The reason for this disagreement may surprise you: There is no universally accepted scientific definition of life. What is life, anyway?

AT A GLANCE

1.1 WHAT IS LIFE?

Biology is the study of life. But what is life? This simple question does not have a simple answer. Although each of us has an intuitive understanding of what it means to say that something is alive, it has proved impossible to devise a precise scientific definition that neatly divides the living from the nonliving. Dictionary definitions typically fall back on phrases like, "the quality that distinguishes living organisms from inorganic objects and dead organisms," without providing much insight as to what that "quality" might be.

Because we don't have a precise definition of life, we must build our definition bit by bit, by describing a set of features. All living things, or **organisms**, share certain characteristics that, taken together, define life:

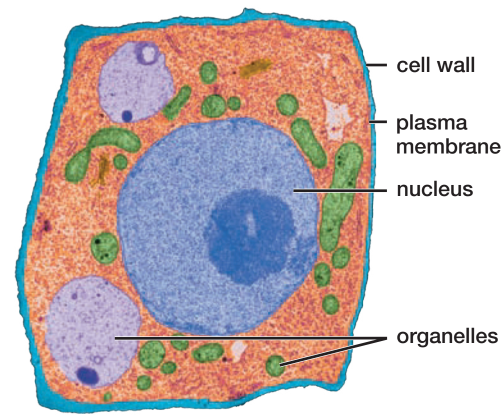
- Organisms actively maintain organized complexity.
- Organisms acquire and use energy and materials.
- Organisms sense and respond to stimuli.
- Organisms grow.
- Organisms reproduce.
- Organisms evolve.

Nonliving objects may possess some of these attributes, but only living things possess them all. In the sections below, we introduce the characteristics of life.

Organisms Actively Maintain Organized Complexity

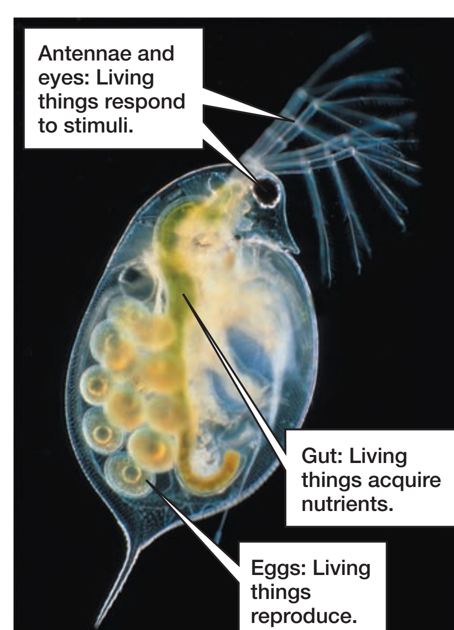
Compared with nonliving matter, living things are highly complex and organized. A nonliving crystal of table salt consists of just two chemical elements, sodium and chlorine, arranged in a precise way; the salt crystal is organized but simple. The nonliving water of an ocean contains atoms of all the naturally occurring elements, but these atoms are randomly distributed; the oceans are complex but not organized. In contrast, even the simplest organisms contain the atoms of dozens of different elements linked together in thousands of specific combinations to form a cell, the basic unit of life (**FIG. 1-1**). Cells are both complex and organized. Each cell contains a huge variety of structures and chemicals enclosed by a thin sheet called the **plasma membrane**.

Cells fall into two main groups: eukaryotic cells and prokaryotic cells. **Eukaryotic** cells contain a variety of **organelles**, which are structures (often surrounded by membrane) that carry out functions such as synthesizing large molecules, digesting food molecules, or obtaining energy. The term "eukaryotic" comes from Greek words meaning "true nucleus." As the name suggests, the **nucleus**, a membrane-enclosed organelle that contains the cell's DNA, is a prominent feature of eukaryotic cells (see Fig. 1-1). **Prokaryotic** cells are



▲ **FIGURE 1-1 The cell is the smallest unit of life** This artificially colored micrograph of a plant cell (a eukaryotic cell) shows a supporting cell wall (blue) that surrounds plant cells. Just inside the cell wall, the plasma membrane (found in all cells) has control over which substances enter and leave. Cells also contain several types of specialized organelles, including the nucleus, suspended within a fluid environment (orange).

simpler than eukaryotic cells; they lack organelles enclosed by membranes. As their name—meaning "before the nucleus"—suggests, a prokaryotic cell's DNA is not confined within a nucleus. All organisms with prokaryotic cells are **unicellular** (exist as single cells); organisms with eukaryotic cells may be unicellular or **multicellular** like the water flea in **FIGURE 1-2**.



▲ **FIGURE 1-2 Properties of life** Evolution has molded the adaptations that allow this water flea to respond to stimuli, acquire nutrients, grow, and reproduce.

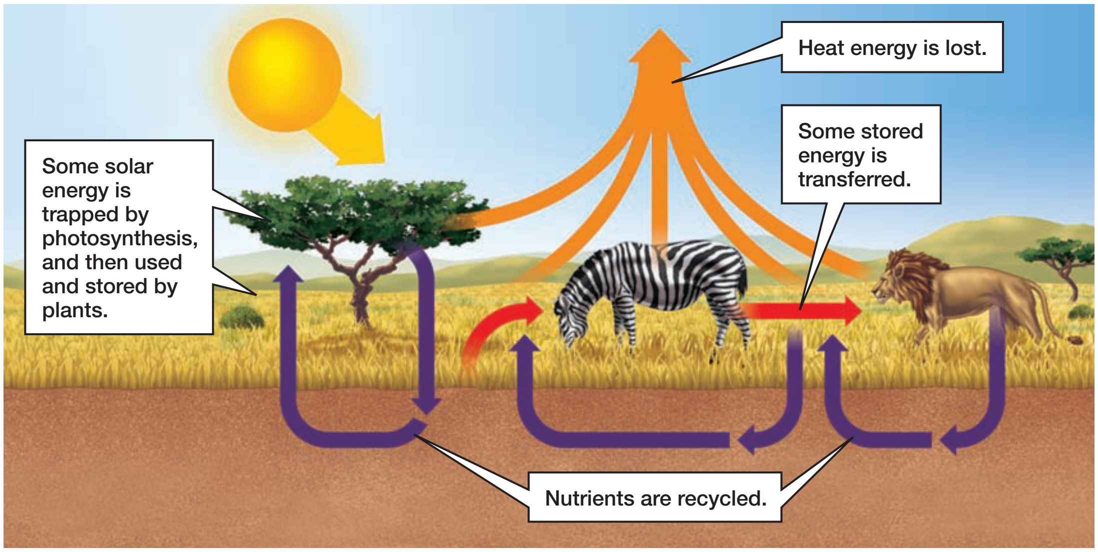


FIGURE 1-3 The flow of energy and the recycling of nonliving nutrients

THINK CRITICALLY
Describe the source of the energy stored in the meat and the bun of a hamburger, and explain how the energy got from the source to the two foodstuffs.

Organisms Acquire and Use Energy and Materials

Organization and complexity tend to break down unless energy is used to maintain them. Living things, representing the ultimate in organized complexity, continuously use energy to maintain themselves. Almost all the energy that sustains life comes from sunlight. Some organisms capture solar energy directly through a process called **photosynthesis**. Photosynthetic organisms (plants and many single-celled organisms) trap and store the sun's energy for their own use. When these organisms are consumed by nonphotosynthetic organisms, this stored energy also powers the consumers. So, energy flows in a one-way path from the sun to photosynthetic organisms to all other forms of life (**FIG. 1-3**). However, some energy is lost as heat at each transfer from one organism to another, making less energy available with each transfer.

The energy that organisms acquire is continuously expended to maintain very specific internal conditions. The ability of an organism to maintain its internal environment within the limits required to sustain life is called **homeostasis**. To maintain homeostasis, cell membranes constantly pump certain substances in and others out. Organisms use both physiological and behavioral mechanisms to maintain the narrow temperature range that allows life-sustaining reactions to occur in their cells (**FIG. 1-4**).

FIGURE 1-4 Organisms maintain relatively constant internal conditions Evaporative cooling by water, both from sweat and from a bottle, helps this athlete maintain his body temperature during vigorous exercise.

Organisms obtain the materials that make up their bodies—such as minerals, water, and other simple chemical building blocks—from the air, water, soil, and bodies of other living things. Because life neither creates nor destroys matter, materials are continuously exchanged and recycled among organisms and their surroundings (see Fig. 1-3).

Organisms Sense and Respond to Stimuli

To obtain energy and nutrients, organisms must sense and respond to stimuli in their environments. Animals use specialized cells to detect light, temperature, sound, gravity, touch, chemicals, and many other stimuli from their external and internal surroundings. For example, when your brain detects both a low level of sugar in your blood (an internal stimulus) and the smell of food (an external stimulus), it causes your mouth to water, or *salivate* (a response) in anticipation of a meal. Plants, fungi, and unicellular organisms respond to stimuli using mechanisms that are effective for their needs (**FIG. 1-5**).

FIGURE 1-5 Bending toward the light Plants perceive and often bend toward light, which provides them with the energy they need to survive.

(a) Dividing *Streptococcus* bacterium (b) Dandelion producing seeds (c) Panda with its baby

▲ **FIGURE 1-6 Organisms reproduce**

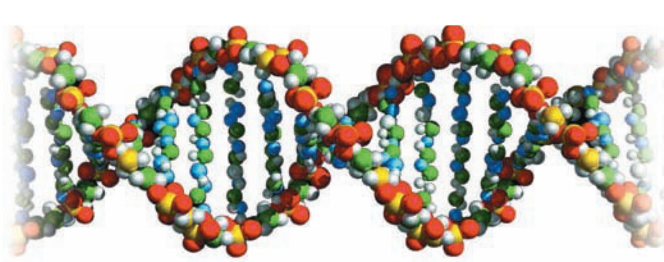
Organisms Grow

At some time in its life, every organism grows. The water flea in Figure 1-2 was once much smaller—the size of one of the eggs you see in its body. Unicellular organisms such as bacteria grow to about double their original size before dividing in half to reproduce. Animals and plants grow by increasing the number of cells in their bodies via cell division, and in some cases by increasing the size of individual cells, as occurs in muscle and fat cells in animals and in food storage cells in plants. In multicellular organisms, growth may be accompanied by *development*, in which a growing organism becomes increasingly complex. For example, a fertilized egg develops into an adult with many complex structures.

Organisms Reproduce

Organisms reproduce in a variety of ways (**FIG. 1-6**); for example, by dividing in half, producing seeds, or bearing live young. The end result is always the same: new individuals of the same type of organism as the parent.

When organisms reproduce, the offspring inherit characteristics of the parents. The instructions for producing these characteristics are carried in the molecule **deoxyribonucleic acid (DNA)**, which is present in every cell and passed on to descendants (**FIG. 1-7**). Specific segments of DNA called **genes** are the basic units of heredity. The complete set of genes contained in each cell provides detailed instructions for building and maintaining an organism, much as a recipe provides instructions for baking a cake.



▲ **FIGURE 1-7 DNA** According to James Watson, codiscoverer of the structure of DNA, "A structure this pretty just had to exist."

Organisms Evolve

All living organisms descended from an ancient common ancestor. Today's diverse forms of life have arisen though a process of descent with modification known as **evolution**. All populations evolve (a population is a group of the same type of organism inhabiting the same area), and every biological structure and process arose through evolution. In the words of biologist Theodosius Dobzhansky, "Nothing in biology makes sense except in the light of evolution."

CHECK YOUR LEARNING

Can you . . .

- explain the characteristics that define life?

CASE STUDY CONTINUED

The Boundaries of Life

Are viruses alive? Viruses do not obtain or use energy or materials, maintain themselves, or grow. Therefore, viruses do not meet the criteria for life. They do, however, possess some lifelike characteristics. For example, viruses respond to stimuli by binding to cells in response to the presence of particular proteins on the cell surface. In addition, viruses reproduce by releasing viral genetic material inside a cell and inducing the infected cell to use its own energy supplies and biochemical machinery to churn out many copies of viral parts, which then assemble into new viruses that emerge from the host cell. Viruses also evolve, often rapidly. How does evolution occur in viruses and organisms?

1.2 WHAT IS EVOLUTION?

The scientific theory of evolution states that all organisms are related by common ancestry and have changed over time. The theory was formulated in the mid-1800s by two English naturalists, Charles Darwin and Alfred Russel Wallace. Since that time, the theory has been supported by a vast amount of evidence from fossils, geology, genetics, molecular biology, biochemistry, and more. Evolution not only accounts for the enormous diversity of life, but also accounts for the remarkable similarities among different types of organisms. For example, people share many features with chimpanzees, and the sequence of our DNA is nearly identical to that of chimpanzees. The similarities provide strong evidence that people and chimps descended from a common ancestor; the differences (**FIG. 1-8**) reflect changes since the evolutionary paths of chimps and humans diverged.

Natural Selection Causes Evolution

The most important process by which evolution occurs is **natural selection**. Natural selection occurs because the characteristics of the different individuals in a population vary, with some individuals possessing traits that help them survive and reproduce more successfully than do others that lack those traits. The individuals with these favorable traits tend to have a greater number of offspring, which inherit those traits. The favorable traits, and the genes that encode them, thus become more common in the population.

For example, consider how natural selection might have influenced the evolution of beaver teeth. In a population of beavers, tooth size varies. Why? Because different beavers may have different versions of the genes that influence tooth size, as a result of past mutations. **Mutations** are changes in genes caused by DNA-copying errors or by damage to DNA. Past beavers with genes for larger teeth might have been able to chew down trees more efficiently, build bigger dams and lodges, and eat more bark than "ordinary" beavers. Because these big-toothed beavers obtained more food and better shelter than their smaller-toothed relatives, they raised more offspring. The offspring inherited their parents' genes for larger teeth. Over time, less-successful, smaller-toothed beavers became increasingly scarce. After many generations, all beavers had large teeth.

▲ **FIGURE 1-8 Chimpanzees and people are closely related**

Natural Selection Results in Adaptation

Structures, physiological processes, or behaviors that arise through natural selection are called **adaptations**. Adaptations help an organism survive and reproduce in a particular environment. Most of the features that we admire so much in other life-forms, such as the fleet, agile limbs of deer, the broad wings of eagles, and the mighty trunks of redwood trees, are adaptations. Adaptations help organisms escape predators, capture prey, reach the sunlight, or accomplish other feats that help ensure their survival and reproduction. The huge array of adaptations found in living things today was molded by natural selection acting on random mutations.

Evolution Can Produce New Species

Although natural selection is responsible for adaptations, it cannot by itself explain how life has diversified to include so many different kinds of organisms. How did deer, eagles, redwoods, people, and the rest of Earth's varied inhabitants all arise from the first single-celled life that appeared billions of years ago? The evolutionary process of diversification begins when a population becomes fragmented. For example, a violent storm carries some members of a population from the mainland to an offshore island. The mainland population and the newly arrived island population will initially consist of individuals of the same **species** (organisms of the same type that can interbreed). But if the island's environment differs from that of the mainland, natural selection will favor different adaptations on the island than on the mainland. These differences may eventually become great enough that the two populations can no longer interbreed. At that point, a new species will have evolved.

Extinction Eliminates Species

What helps an organism survive today may become a liability in the future. If environments change—for example, as global climate change occurs—the traits that are adaptive will change as well. For example, in a location where temperatures are rising, if a random mutation helps an organism survive and reproduce in a warmer climate, the mutation will be favored by natural selection and will become more common in the population with each new generation.

If mutations that are adaptive do not occur, a changing environment may doom a species to **extinction**—complete elimination. Dinosaurs flourished for 100 million years, but

FIGURE 1-9 A fossil from a newly discovered dinosaur, *Titanosaurus* The most widely accepted hypothesis for the extinction of dinosaurs about 66 million years ago is a massive meteorite strike that rapidly and radically altered their environment. This thigh bone, estimated to be 95 million years old, is from a plant-eating giant with an estimated length of 130 feet (40 meters) and a weight of about 176,000 pounds (80 metric tons).

THINK CRITICALLY The largest dinosaurs were plant-eaters. Based on Figure 1-3, can you suggest a reason why?

because they did not adapt to changing conditions, they became extinct (**FIG. 1-9**). In recent decades, human activities such as burning fossil fuels and converting tropical forests to farmland have drastically accelerated the rate of environmental change, and consequently the rate of extinction has increased dramatically.

CHECK YOUR LEARNING

Can you . . .

- explain how natural processes lead inevitably to evolution by natural selection?
- explain what mutations are and the role they play in evolution?
- describe how species arise and how they become extinct?

CASE STUDY CONTINUED

The Boundaries of Life

One lifelike property of viruses is their capacity to evolve. Viruses may evolve by natural selection to become more deadly, become more easily transmitted, or gain the ability to infect new hosts. The genetic material of many viruses, including Ebola, HIV, and flu, is copied very inefficiently, resulting in a mutation rate that is about 1,000 times higher than that of the average animal cell. One consequence of this high mutation rate is that viruses evolve rapidly, quickly acquiring adaptations that help them resist both our immune system and antiviral drugs. Rapid viral evolution explains why flu shots must be updated every year and why HIV has become resistant to the drugs used to treat it. Because natural selection in a population exposed to an antiviral drug will inevitably favor viruses with mutations that make them resistant to the drug, HIV patients are given "cocktails" of three or four different drugs. A virus would be resistant to all the drugs only if it carried multiple different resistance mutations, which is very unlikely.

1.3 HOW DO SCIENTISTS STUDY LIFE?

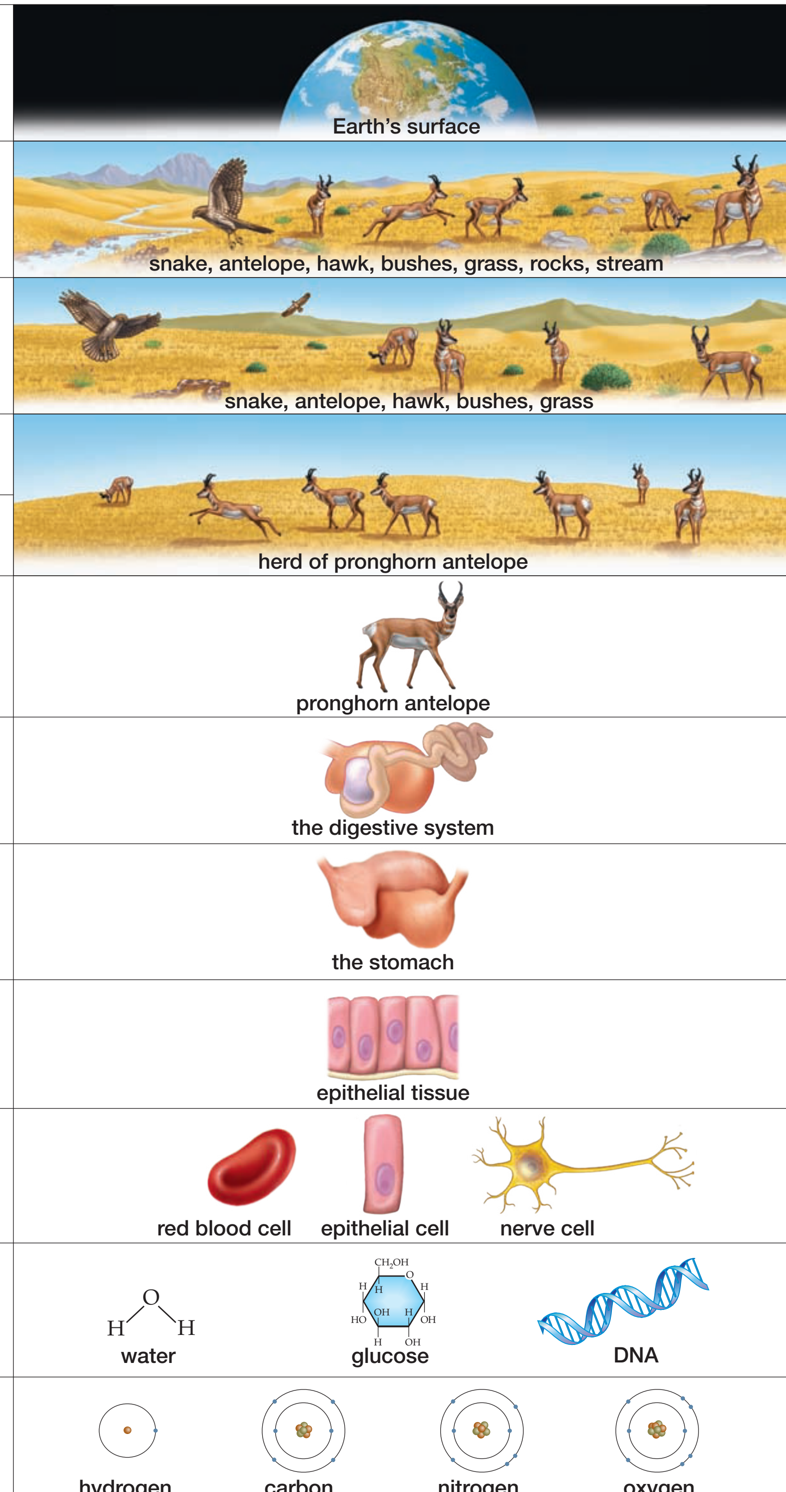
The science of biology encompasses many different areas of inquiry. In fact, biology is not a single scientific discipline, but many—linked by the amazing complexity of life.

Life Can Be Studied at Different Levels

Biologists often view the living world as a series of levels of organization, with each level providing the building blocks for the one above it (**FIG. 1-10**). At the lowest level of organization are atoms. An **atom** is the smallest particle of an element that retains all the properties of the element (an element is a substance that cannot be broken down or converted into a simpler substance). For example, the smallest possible unit of a piece of gold is an individual gold atom. Atoms may combine to form **molecules**; for example, one oxygen atom can combine with two hydrogen atoms to form a molecule of water. Complex biological molecules containing carbon atoms form the building blocks of **cells**, which are the basic units of life. In multicellular organisms, cells of a similar type may combine to form **tissues**, such as the epithelial tissue that lines the stomach. Different types of tissues, in turn, unite to form functional units called **organs**, such as the entire stomach. The grouping of two or more organs that work together to perform a specific body function is called an **organ system**; for example, the stomach is part of the digestive system. Multiple organ systems work together within multicellular organisms. Organisms of the same species that live in a defined area form a **population**. A collection of all the populations of organisms that are similar enough to interbreed forms a species. The different species that live in an area and interact with one another constitute a **community**. A community and the nonliving environment that surrounds it make up an **ecosystem**. Finally, all the ecosystems on Earth together compose the **biosphere**.

One of the first choices a biologist makes when designing an experiment is the appropriate level of organization at

Biosphere	All life on Earth and the nonliving portions of Earth that support life
Ecosystem	A community together with its nonliving surroundings
Community	Populations of different species that live in the same area and interact with one another
Species	All organisms that are similar enough to interbreed
Population	All the members of a species living in the same area
Multicellular organism	An individual living thing composed of many cells
Organ system	Two or more organs working together in the execution of a specific bodily function
Organ	A structure usually composed of several tissue types that form a functional unit
Tissue	A group of similar cells that perform a specific function
Cell	The smallest unit of life
Molecule	A combination of atoms
Atom	The smallest particle of an element that retains the properties of that element



▲ **FIGURE 1-10 Levels of biological organization** Each level provides building blocks for the one above it, which has new properties that emerge from the interplay of the levels below.

THINK CRITICALLY Which level of organization would be most appropriate for investigating how photosynthesis converts solar energy to stored energy?

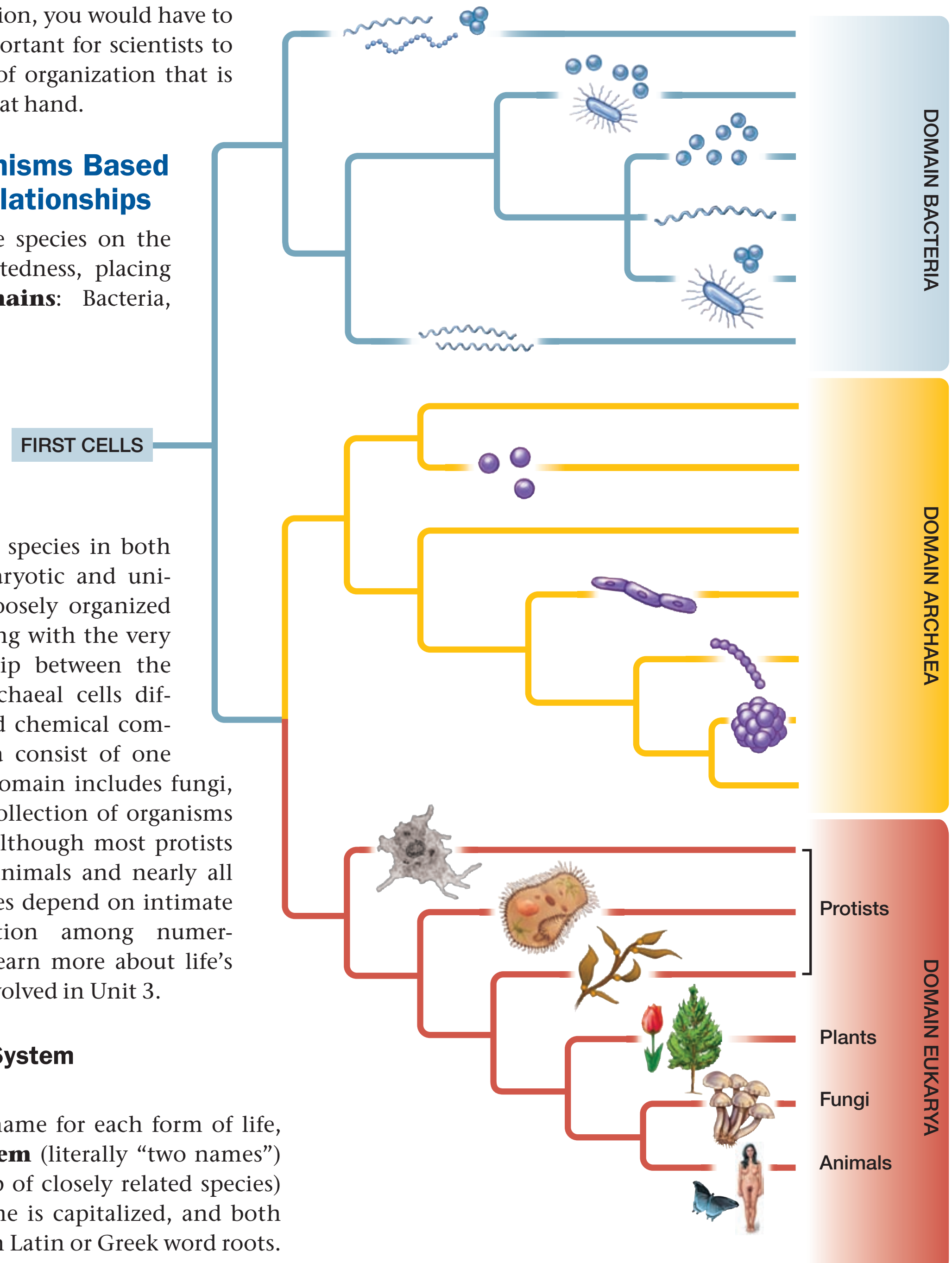
which to study a problem. This decision is ordinarily based on the question to be answered. For example, if you wanted to know how frogs make croaking sounds, you would study organs within the frog's body. The question of how frogs croak would be impossible to answer if you focused on frog cells or frog communities. On the other hand, if you wanted to know whether global climate change is reducing the number of frogs in the world, it would do you no good to study frog organs. To answer that question, you would have to study frog populations. It is important for scientists to recognize and choose the level of organization that is most appropriate to the question at hand.

Biologists Classify Organisms Based on Their Evolutionary Relationships

Scientists classify Earth's diverse species on the basis of their evolutionary relatedness, placing them into three major **domains**: Bacteria, Archaea, and Eukarya (**FIG. 1-11**).

Cell Structure Distinguishes the Bacteria, Archaea, and Eukarya

Members of the three domains can be distinguished by the characteristics of their cells. All species in both Bacteria and Archaea are prokaryotic and unicellular, although some form loosely organized strands, mats, or films. In keeping with the very distant evolutionary relationship between the two domains, bacterial and archaeal cells differ significantly in structure and chemical composition. Organisms in Eukarya consist of one or more eukaryotic cells. This domain includes fungi, plants, animals, and a diverse collection of organisms collectively known as *protists*. Although most protists are unicellular, all plants and animals and nearly all fungi are multicellular; their lives depend on intimate communication and cooperation among numerous specialized cells. You will learn more about life's incredible diversity and how it evolved in Unit 3.



▲ **FIGURE 1-11 The domains of life**

Biologists Use the Binomial System to Name Organisms

To provide a unique scientific name for each form of life, biologists use a **binomial system** (literally "two names") consisting of the genus (a group of closely related species) and the species. The genus name is capitalized, and both names are italicized and based on Latin or Greek word roots. The animal in Figure 1-2 has the common name "water flea," but there are many types of water fleas, and people who study them need to be precise. So this water flea has been given the scientific name *Daphnia longispina*, placing it in the genus *Daphnia* (which includes many similar species of water fleas) and the species *longispina* (referring to its long spine, visible in Figure 1-2). People are classified as *Homo sapiens*; we are the only surviving members of our genus.

CHECK YOUR LEARNING

Can you . . .

- describe the levels of biological organization?
- explain how scientists categorize and name diverse forms of life?
- describe some differences between the three domains of life?

1.4 WHAT IS SCIENCE?

Science can be defined as systematic inquiry, through observation and experiment, into all aspects of the physical universe.

Science Is Based on General Underlying Principles

Three basic principles provide the foundation for scientific inquiry. The first is that all events can be traced to natural causes. In ancient times, it was common to believe that supernatural forces were responsible for natural events. For example, ancient Greeks believed that lightning bolts were weapons hurled by the god Zeus and that epileptic seizures were the result of a visit from the gods. Today, we understand from scientific research that lightning is a massive electrical discharge, and epilepsy is a brain disorder caused by uncontrolled firing of nerve cells. Science is an unending quest to discover the causes of phenomena that we don't yet understand.

The second principle of science is that natural laws do not change over time or distance. The laws of gravity, for example, are the same today as they were 10 billion years ago, and they apply everywhere in our universe.

The third principle is that scientific findings are "value neutral." Science, in its ideal form, provides us with facts that are not influenced by subjective values; scientific data are independent of any belief system. For example, science can objectively describe the events that occur when a human egg is fertilized, but cannot answer the subjective, value-based question of whether a fertilized egg is a person.

The Scientific Method Is an Important Tool of Scientific Inquiry

To learn about the world, scientists in many disciplines, including biology, use the **scientific method**. This method consists of six interrelated elements: observation, question, hypothesis, prediction, experiment, and conclusion. Scientific inquiry begins with an **observation** of a phenomenon. The observation, in turn, leads to a **question** about what was observed. After carefully studying earlier investigations, thinking, and often conversing with colleagues, the investigator forms a hypothesis. A **hypothesis** is a proposed explanation for the observation, an answer to the question. To be useful, a hypothesis must lead to a **prediction**, which is an outcome expected after testing if the hypothesis is correct. The prediction is tested by carefully designed additional observations or carefully controlled manipulations called **experiments**. Experiments produce results that either support or refute the hypothesis, allowing the scientist to reach a **conclusion** about whether the hypothesis is valid or not. For the conclusion to be valid, the experiment and its results must be repeatable not only by the original researcher but also by others.

We use less-formal versions of the scientific method in our daily lives. For example, suppose you are late for an important date, so you rush to your car, turn the ignition key, and make the *observation* that the car won't start. Your *question*, "Why won't the car start?" leads to a *hypothesis*: The battery is dead. This hypothesis leads to the *prediction* that a jump-start will solve the problem. You *experiment* by attaching jumper cables from your roommate's car battery to your own. The result? Your car starts immediately, leading to the *conclusion* that your experiment supported your hypothesis about the dead car battery.

Experiments Incorporate Controls

Many experiments test the hypothesis that a single factor, or **variable**, is the cause of an observed phenomenon. The most effective test of such a hypothesis is usually an experiment in which only a single variable is manipulated. In most experiments, however, it is difficult to be certain that the manipulation did not inadvertently change more than one factor. For example, in the car battery experiment, jump-starting the car might have both delivered a charge to the battery and knocked some corrosion off the battery terminal that was preventing the battery from delivering power—the battery might actually have been fully charged. To guard against the effects of unnoticed variables, experiments usually also include **controls**, sections of the experiment in which no variable is changed. Results from the control condition can then be compared with those from the experimental condition (see "Doing Science: Controlled Experiments Provide Reliable Data" on page 10). In real experiments, scientists must attempt to control for all the possible effects of any manipulation they perform, so frequently more than one control is needed.

Experiments Are Not Always Possible

A well-designed experiment is usually the most convincing way to test a hypothesis, but biology includes many hypotheses that are not suited to experimental tests. For example, evolutionary biologists often ask questions about events from the historical past. Consider, for example, the hypothesis that the ancestors of today's birds were dinosaurs. These hypothesized ancestors went extinct long ago, of course, and there is no experiment that can demonstrate how they evolved millions of years ago. Nonetheless, the biologists who study this question do apply the other parts of the scientific method, using their hypotheses to make testable predictions. For example, if dinosaurs were the ancestors of birds, then we predict the discovery of fossils of dinosaurs with feathers. Such fossils have indeed been found, providing evidence that supports the hypothesis.

In some cases, an experiment would be theoretically possible but is impractical or unethical. For example, consider the hypothesis that smoking causes lung cancer in people. In principle, we could test this hypothesis with an experiment that divided a large sample of people who had never smoked into two groups. The members of one group would be required to smoke a pack of cigarettes each day, and the members of the other group would serve as controls and would not be allowed to smoke. After, say, 20 years, we could count the number of cases of lung cancer in each group. Such an experiment would provide a powerful test of the hypothesis but would, needless to say, be highly unethical. Again, though, an inability to experiment does not mean that the scientific method must be abandoned, because predictions can be tested by careful observation. If smoking causes lung cancer, then we predict that a random sample of smokers should contain more lung cancer victims than a comparable sample of nonsmokers. Many studies have indeed found an association between smoking and lung cancer, evidence that supports the hypothesis that smoking causes cancer.

DOING Science Controlled Experiments Provide Reliable Data

A classic experiment by the Italian physician Francesco Redi (1626–1697) beautifully demonstrates the scientific method and helps to illustrate the scientific principle that all events can be traced to natural causes. Redi investigated why maggots (fly larvae) appear on spoiled meat. In Redi's time, refrigeration was unknown, and meat was stored in the open. Many people of that time believed that the appearance of maggots on meat was evidence of **spontaneous generation**, the emergence of life from nonliving matter.

Redi *observed* that flies swarm around fresh meat and that maggots appear on meat left out for a few days. On the basis of this observation, he posed the *question* of whether there was a connection between the presence of flies and the appearance of maggots. He then formed a testable *hypothesis*: Flies produce maggots. This led to the *prediction* that keeping flies off the meat would prevent maggots from appearing. In his *experiment*, Redi wanted to test one variable—the access of flies to the meat. Therefore, he placed similar pieces of meat in each of two clean jars. He left one jar open (the control jar) and covered the other with gauze to keep out flies (the experimental jar). He did his best to keep all the other conditions the same (for example, the type of jar, the type of meat, and the temperature). After a few days, he observed maggots on the meat in the open jar but saw none on the meat in the covered jar. Redi *concluded* that his hypothesis was correct and that maggots are produced by flies, not by the nonliving meat (**FIG. E1-1**). Only through this and other controlled experiments could the age-old belief in spontaneous generation be laid to rest.

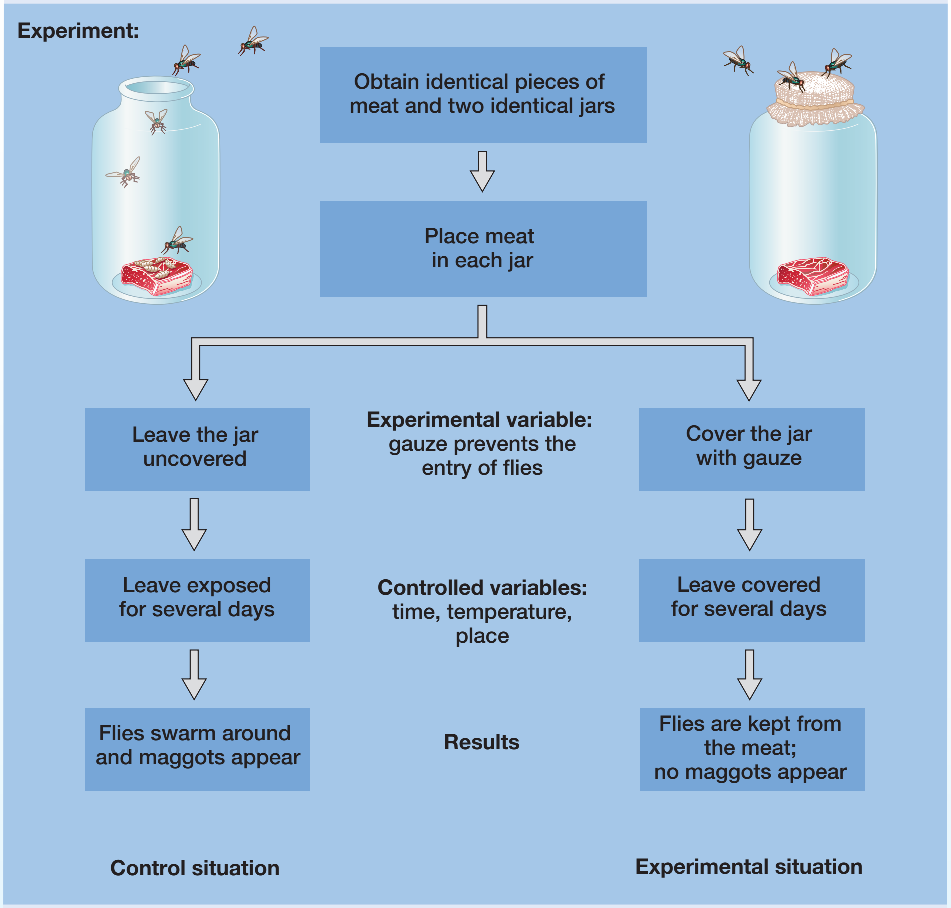
Today, more than 300 years later, scientists still perform controlled experiments. Consider the experiments of Malte Andersson, who investigated the long tails of male widowbirds. Andersson *observed* that male, but not female, widowbirds have extravagantly long tails, which they display while flying across African grasslands. Andersson asked the *question*, "Why do male birds have such long tails?" His *hypothesis* was that females prefer to mate with long-tailed males, and so these males have more offspring, who inherit the genes for long tails. Andersson *predicted* that if his hypothesis were true, more females would build nests on the territories of males with artificially lengthened tails than on the territories of males with artificially shortened tails. To test this prediction, he captured some males, trimmed their tails to about half their original length, and released them (*experimental* group 1). He took another group of males and glued on the tail feathers that he had removed from the first group, creating exceptionally long tails (*experimental* group 2). Then, in *control* group 1, he cut the tail feathers but then glued them back in place (to control for the effects of capturing the birds and manipulating their feathers). In *control* group 2, he simply captured and released a group of male birds to control for behavioral changes caused by the stress of being caught and handled.

Observation: Flies swarm around meat left in the open; maggots appear on the meat.

Question: Where do the maggots on the meat come from?

Hypothesis: Flies produce the maggots.

Prediction: IF the hypothesis is correct, THEN keeping the flies away from the meat will prevent the appearance of maggots.



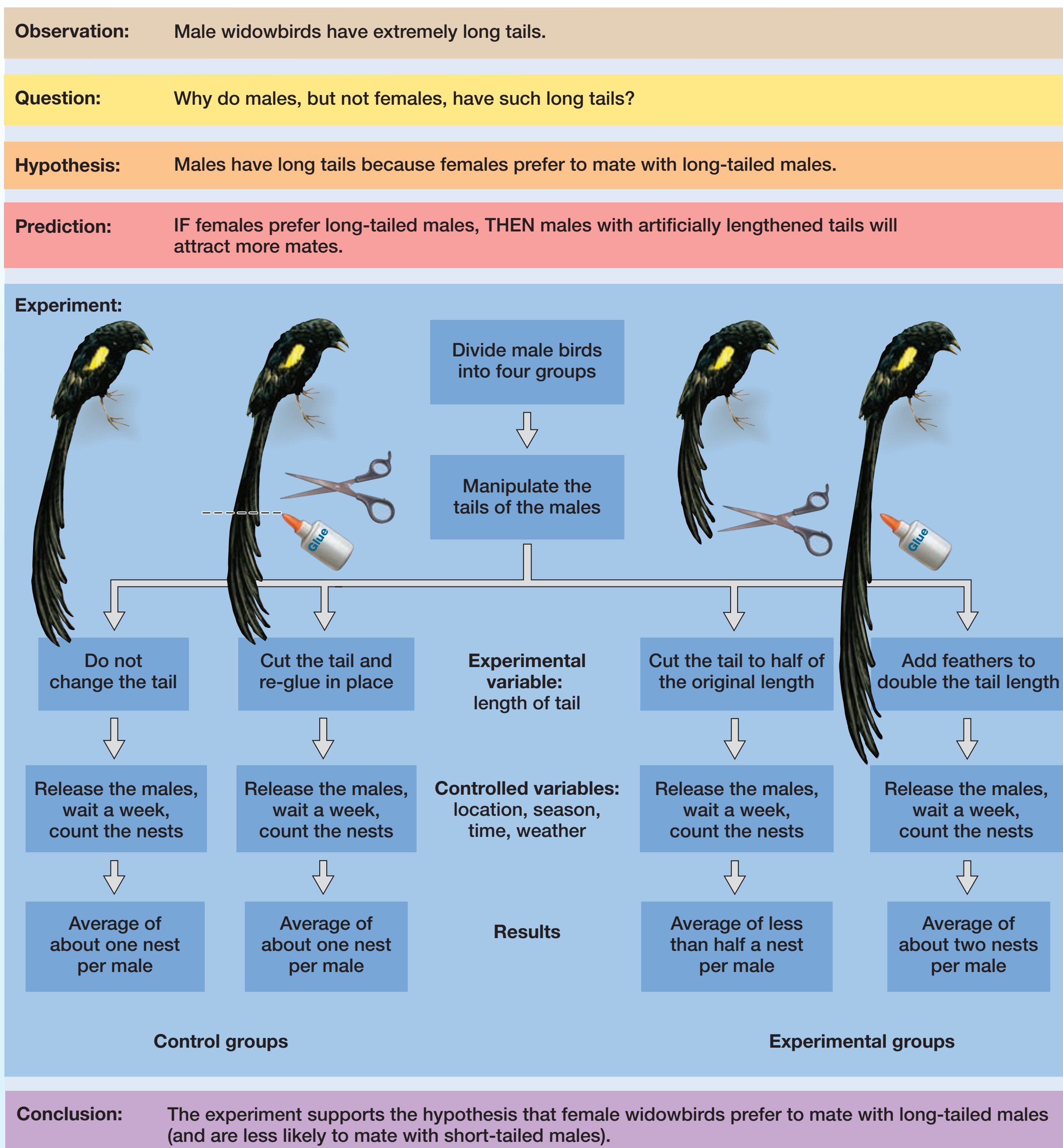
Conclusion: The experiment supports the hypothesis that flies are the source of maggots and that spontaneous generation of maggots does not occur.

FIGURE E1-1 The experiment of Francesco Redi illustrates the scientific method

Later, Andersson counted the number of nests that females had built on each male's territory, which indicated how many females had mated with that male. He found that males with lengthened tails had the most nests on their territories, males with shortened tails had the fewest, and control males (with normal-length tails, either untouched or cut and glued together) had an intermediate number (**FIG. E1-2**). Andersson *concluded* that his results supported the hypothesis that female widowbirds prefer to mate with long-tailed males.

Although controlled experiments like those of Redi and Andersson are the gold standard of scientific evidence, scientific research does not always include all the elements we have described here. For example, the early stages of a research project might consist of exploratory observations, conducted without a specific hypothesis or prediction. In some scientific fields, such as paleontology (the study of fossils), experiments are not even possible. As we explore examples of scientific investigation in "Doing Science" boxes later in this text, you will see different variants of the scientific method. In most cases, however, the examples will feature a scientific question (indicated by the heading "What Question Was Asked?"), the methods used to collect evidence ("How Was Evidence Gathered?"), and the results and conclusions ("What Was Learned?").

THINK CRITICALLY Did Redi's experiment convincingly demonstrate that flies produce maggots? What kind of follow-up experiment would help confirm the source of maggots?



▲ **FIGURE E1-2 The experiment of Malte Andersson**

▲ **FIGURE 1-12 Researchers share their results at a scientific meeting** Posters are often used used to summarize results when scientists gather to present and discuss their findings.

Science Requires Repeatability and Communication

If an experiment's result is valid, the experiment will yield the same result each time it is performed. Thus, to ensure validity, researchers perform multiple repetitions of an experiment, setting up several replications of each control condition and each experimental condition. Scientists are most confident in an experimental result when it has also been replicated by researchers other than the ones who made the initial finding.

Even the best experiment is useless if it is not communicated (**FIG. 1-12**). Good scientists publish their results, explaining their methods in detail so others can repeat and build on their experiments.

Scientific Theories Have Been Thoroughly Tested

Scientists use the word "theory" in a way that differs from its everyday usage. If Dr. Watson asked Sherlock Holmes, "Do you have a theory as to the perpetrator of this foul deed?" then in scientific terms, he would be asking Holmes for a hypothesis—a proposed explanation based on clues that provide incomplete evidence. A **scientific theory**, in contrast, is a general and reliable explanation of important natural phenomena that has been developed through extensive and reproducible observations and experiments. In short, a scientific theory is best described as a **natural law**, a basic principle derived from the study of nature that has never been disproven by scientific inquiry. For example, scientific theories such as the atomic theory (that all matter is composed of atoms) and the theory of gravitation (that objects exert attraction for one another) are fundamental to the science of physics. Likewise, the **cell theory** (that all living organisms are composed of cells) and the theory of evolution are fundamental to the study of biology.

Scientists describe fundamental principles as "theories" rather than "facts" because even scientific theories can potentially be disproved, or falsified. If compelling evidence arises that renders a scientific theory invalid, that theory must be modified or discarded. A modern example of the need to modify basic principles in the light of new scientific evidence is the discovery of prions, which are infectious proteins (see Chapter 3). Before the early 1980s, all known infectious disease agents replicated using instructions from genetic material. Then in 1982, neurologist Stanley Prusiner published evidence that scrapie (an infectious disease of sheep that causes brain degeneration) is actually triggered and transmitted by a protein and has no genetic material. Infectious proteins were unknown to science, and Prusiner's results were met with widespread skepticism. It took nearly two decades of further research to convince most of the scientific community that a protein alone could act as an infectious disease agent. Prions are now known to cause mad cow disease and two fatal human brain disorders. Prusiner was awarded the Nobel Prize in Physiology or Medicine for his pioneering work. By accepting, on the basis of accumulated scientific evidence, the conclusion

Have You Ever Wondered ...

Why Scientists Study Obscure Organisms?

Some people are puzzled by the willingness of governments to fund research that seems obscure or pointless. One reason to fund such research is that no one can say where a research idea might lead, and allowing scientists to follow their curiosity may lead to unexpected and valuable findings. Research on seemingly unimportant organisms like fruit flies, bacteria from hot springs, sea jellies, Gila monsters, and burdock burrs has improved people's lives. Fruit flies have been used for over 100 years to study how genes influence traits. Their genes are similar enough to ours that studying fruit flies has helped us to better understand many human genetic diseases. Research on an obscure bacterium found in hot springs revealed a protein that is now an essential component of a laboratory process that rapidly copies DNA. Thanks to this discovery, the DNA in a few skin cells left at a crime scene can generate a sample large enough to be compared to the DNA of a suspect. Scientific investigation of a sea jelly uncovered a fluorescent protein that can be attached to a gene, protein, or virus, making it glow and allowing researchers to monitor its activity. A protein found in a Gila monster's venomous saliva is now used as a drug that helps diabetics maintain more constant blood sugar levels. And what did microscopic examination of a burr lead to? The inspiration for Velcro.

Gila monster

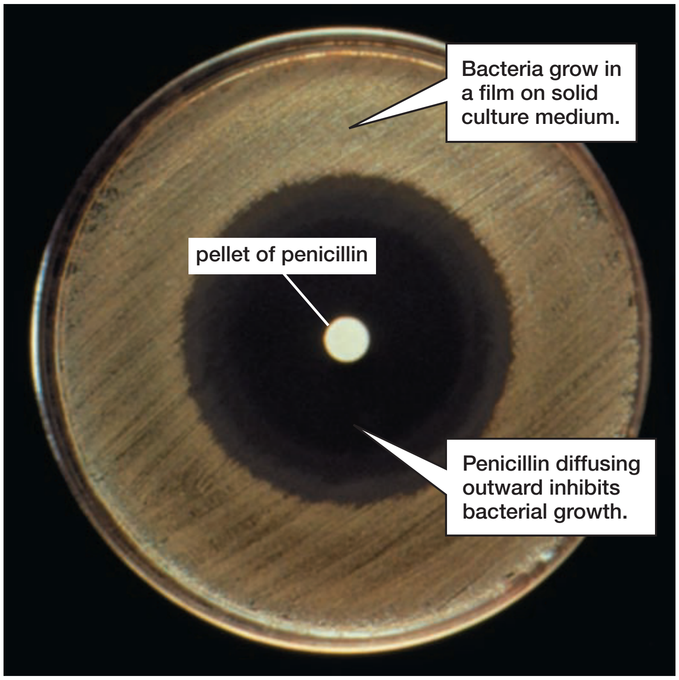
that prions can act as infectious proteins, scientists maintained the integrity of the scientific process while expanding our understanding of how diseases can occur. Ongoing scientific inquiry continuously tests scientific theories.

Science Is a Human Endeavor

Scientists are people, driven by the pride, fears, and ambition common to humanity. Accidents, lucky guesses, competition with other scientists, and, of course, the intellectual curiosity of individual scientists all contribute to scientific advances. Even mistakes can play a role. Let's consider an actual case.

Microbiologists often study pure cultures—a single type of bacterium grown in sterile, covered dishes free from contamination by other bacteria and molds. At the first sign of contamination, a culture is usually thrown out, often with mutterings about sloppy technique. In the late 1920s, however, Scottish bacteriologist Alexander Fleming turned a ruined bacterial culture into one of the greatest medical advances in history.

One of Fleming's cultures became contaminated with a mold (a type of fungus) called *Penicillium*. But instead of discarding the dish, Fleming observed that no bacteria were growing near the mold (**FIG. 1-13**). He asked the question, "Why aren't bacteria growing in this region?" Fleming then formulated the hypothesis that *Penicillium* releases a substance that kills bacteria, and he predicted that a solution in which the mold had grown would contain this substance and kill bacteria. To test this hypothesis, Fleming performed an experiment. He grew *Penicillium* in a liquid nutrient broth and then filtered out the mold and poured some of the mold-free broth on a plate with a pure bacterial culture. Sure enough, something in the liquid killed the bacteria, supporting his hypothesis. This (and more experiments that confirmed his results) led to the conclusion that *Penicillium* secretes a substance that kills bacteria. Further research into these mold extracts resulted in the production of the first antibiotic—penicillin.



▲ **FIGURE 1-13 Penicillin kills bacteria** Alexander Fleming observed similar inhibition of bacterial growth around colonies of *Penicillium* mold.

▲ **FIGURE 1-14 Adaptations in lupine flowers** Understanding life helps people notice and appreciate the small wonders at their feet. (Inset) A lupine flower deposits pollen on a foraging bee's abdomen.

Fleming's experiments are a classic example of the scientific method, but they would never have happened without the combination of a mistake, a chance observation, and the curiosity to explore it. The outcome has saved millions of lives. As French microbiologist Louis Pasteur said, "Chance favors the prepared mind."

Biology Illuminates Life

Some people feel that science promotes a cold, clinical view of life and that scientific explanations of the natural world rob us of wonder and awe. Nothing could be further from the truth. Biological knowledge only deepens our appreciation of nature's majesty.

Let's look closely at lupine flowers. Their two lower petals form a tube surrounding both male and female reproductive parts (**FIG. 1-14**). In young flowers, the weight of a bee on this tube forces pollen grains (which carry sperm) out of the tube and onto the bee's abdomen. In older lupine flowers that are ready to be fertilized, the female part grows and emerges through the end of the tube. When a pollen-dusted bee visits, it deposits some pollen on the female organ, allowing the lupine to produce the seeds of the next generation.

Do these insights detract from our appreciation of lupines? Far from it. There is added delight in watching and understanding the intertwined form and function of bee and flower that resulted as these organisms evolved together. Soon after learning the lupine's pollination mechanism, two of the authors of this text crouched beside a wild lupine to watch it happen. An elderly man passing by stopped to ask what they were looking at so intently. He listened with interest as they explained about what happened when a bee landed on the lupine's petals, and he immediately went to observe another patch of lupines where bees were foraging. He, too, felt the heightened sense of appreciation and wonder that comes with understanding.

Throughout this text, we try to convey that biology is not just another set of facts to memorize. It is a pathway to understanding yourself and the life around you. It is also important to recognize that biology is not a completed work, but an ongoing exploration. As Alan Alda, best known for playing "Hawkeye" in the TV show *M*A*S*H*, stated: "With every door into nature we nudge open, 100 new doors become visible."

CHECK YOUR LEARNING

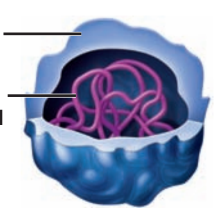
Can you . . .

- describe the principles underlying science?
- outline the scientific method?
- explain why controls are crucial in biological studies?
- explain why fundamental scientific principles are called theories?

CASE STUDY REVISITED

The Boundaries of Life

If viruses aren't living organisms, what are they? A virus by itself is an inert particle far simpler than even the least complex cell.



▲ **FIGURE 1-15 A smallpox virus**

The simplest viruses, such as the ones that cause smallpox (**FIG. 1-15**), consist of nothing more than a protein coat surrounding a small amount of genetic material. The uncomplicated structure of viruses has made it possible for researchers to synthesize viruses in the laboratory, using off-the-shelf chemicals and the instructions contained in viral genetic material. The first virus to be synthesized was the small, simple poliovirus. This feat was accomplished in 2002 by Eckard Wimmer and co-workers at Stony Brook University, who titled their work, "The Test-Tube Synthesis of a Chemical Called Poliovirus."

Did these researchers create life in the laboratory? A few scientists would say, "yes," defining life by its ability to reproduce and to evolve. Wimmer himself describes viruses as entities that switch between a nonliving phase outside the cell and a living phase inside. Although most scientists agree that viruses aren't alive and support the definition of life presented in this text, the controversy continues. As virologist Luis Villarreal puts it, "Viruses are parasites that skirt the boundaries between life and inert matter."

CONSIDER THIS When Wimmer and coworkers announced that they had synthesized the poliovirus, controversy erupted. Some people feared that the newly developed methods could be used by terrorists to synthesize deadly and highly contagious viruses. The researchers responded that they were merely applying current knowledge and techniques to demonstrate that viruses are basically chemical entities that can be synthesized in the laboratory. Do you think scientists should synthesize viruses or other agents that can cause infectious disease? What are the implications of forbidding such research?

CHAPTER REVIEW

Go to **Mastering Biology** to access the Pearson eText, vocabulary review, practice quizzes, activities, videos, current events, and more.

*Answers to **Think Critically and Thinking Through the Concepts** questions can be found in the **Answers** section at the back of the book.*

Summary of Key Concepts

1.1 What Is Life?

Living organisms actively maintain organized complexity, perceive and respond to stimuli, grow, reproduce, and evolve. Organisms also acquire and use materials and energy. Materials are obtained from other organisms or the nonliving environment and are repeatedly recycled. Energy must be continuously captured from sunlight by photosynthetic organisms, whose bodies supply energy to all other organisms.

1.2 What Is Evolution?

Evolution is the scientific theory that modern organisms descended, with changes, from earlier organisms. Evolution occurs as a consequence of (1) genetic differences among members of a population; (2) inheritance of these differences by offspring; and

(3) natural selection favoring individuals with the characteristics that are the best adaptations to the organism's environment.

1.3 How Do Scientists Study Life?

Scientists identify a hierarchy of levels of organization, each more encompassing than those beneath (see Fig. 1-10). Biologists categorize organisms into three domains: Archaea, Bacteria, and Eukarya. Members of Archaea and Bacteria consist of single prokaryotic cells, but fundamental structural and chemical differences distinguish them. Members of Eukarya are composed of one or more eukaryotic cells. Organisms are assigned scientific names that identify them as a unique species within a specific genus.

1.4 What Is Science?

Science is based on three principles: (1) all events can be traced to natural causes that can be investigated; (2) the laws of nature are unchanging; and (3) scientific findings are independent of values except honesty in reporting data. Knowledge in biology is acquired through the scientific method, in which an observation leads to a question that leads to a hypothesis. The hypothesis generates a prediction that is then tested by controlled experiments or precise observation. The experimental results, which must be repeatable, lead to a conclusion that either supports or refutes the hypothesis. A scientific theory is a general explanation of natural phenomena developed through extensive and reproducible experiments and observations.

Thinking Through the Concepts

Bloom's: Remembering, Understanding

Multiple Choice

1. Evolution is
   a. a belief.
   b. a scientific theory.
   c. a hypothesis.
   d. never observed in the modern world.

2. Which of the following is *not* true of science?
   a. Science is based on the premise that all events can be traced to natural causes.
   b. Important science can be based on chance observations.
   c. A hypothesis is basically a wild guess.
   d. Scientific theories can potentially be disproved.

3. Which of the following statements about natural selection is *not* true?
   a. Natural selection favors the same traits in all environments.
   b. Natural selection produces adaptations.
   c. Natural selection affects only traits that are inherited.
   d. Natural selection acts on variation that is caused by mutations.

4. Viruses
   a. have DNA confined in a nucleus.
   b. are relatively rare compared to living organisms.
   c. do not evolve.
   d. require a host cell to reproduce.

5. Which one of the following is true?
   a. The presence of a cell nucleus distinguishes Bacteria from Archaea.
   b. All cells are surrounded by a plasma membrane.
   c. All members of Eukarya are multicellular.
   d. Viruses are the simplest cells.

Fill-in-the-Blank

1. Organisms respond to _____________. Organisms acquire and use _____________ and _____________ from the environment. Organisms are composed of cells whose structure is both _____________ and _____________. Populations of organisms _____________ over time.

2. The smallest particle of an element that retains all the properties of that element is a(n) _____________. The smallest unit of life is the _____________. Cells of a specific type within multicellular organisms combine to form _____________. A(n) _____________ consists of all the members of a species within a defined area. A(n) _____________ consists of all the interacting populations within the same area. A(n) _____________ consists of the community and its nonliving surroundings.

3. A(n) _____________ is a general explanation of natural phenomena supported by extensive, reproducible tests and observations. In contrast, a(n) _____________ is a proposed explanation for observed events. To answer specific questions about life, biologists use a general process called the _____________.

4. An important scientific theory that explains why organisms are at once so similar and so diverse is the theory of _____________. This theory explains life's diversity as having originated primarily through the process of _____________.

5. The molecule that guides the construction and operation of an organism's body is called (complete term) _____________, abbreviated as _____________. This large molecule contains discrete segments with specific instructions; these segments are called _____________.

Review Questions

1. What properties are shared by all forms of life?

2. Why do organisms require energy? Where does the energy come from?

3. Define *evolution*, and explain the process of natural selection.

4. What are the three domains of life?

5. What are some differences between prokaryotic and eukaryotic cells? In which domain(s) is each found?

6. What basic principles underlie scientific inquiry?

7. What is the difference between a scientific theory and a hypothesis? Why do scientists refer to basic scientific principles as "theories" rather than "facts"?

8. What factors did Redi control for in his open jar of meat? What factors did Andersson control for?

9. List the steps in the scientific method with a brief description of each step.

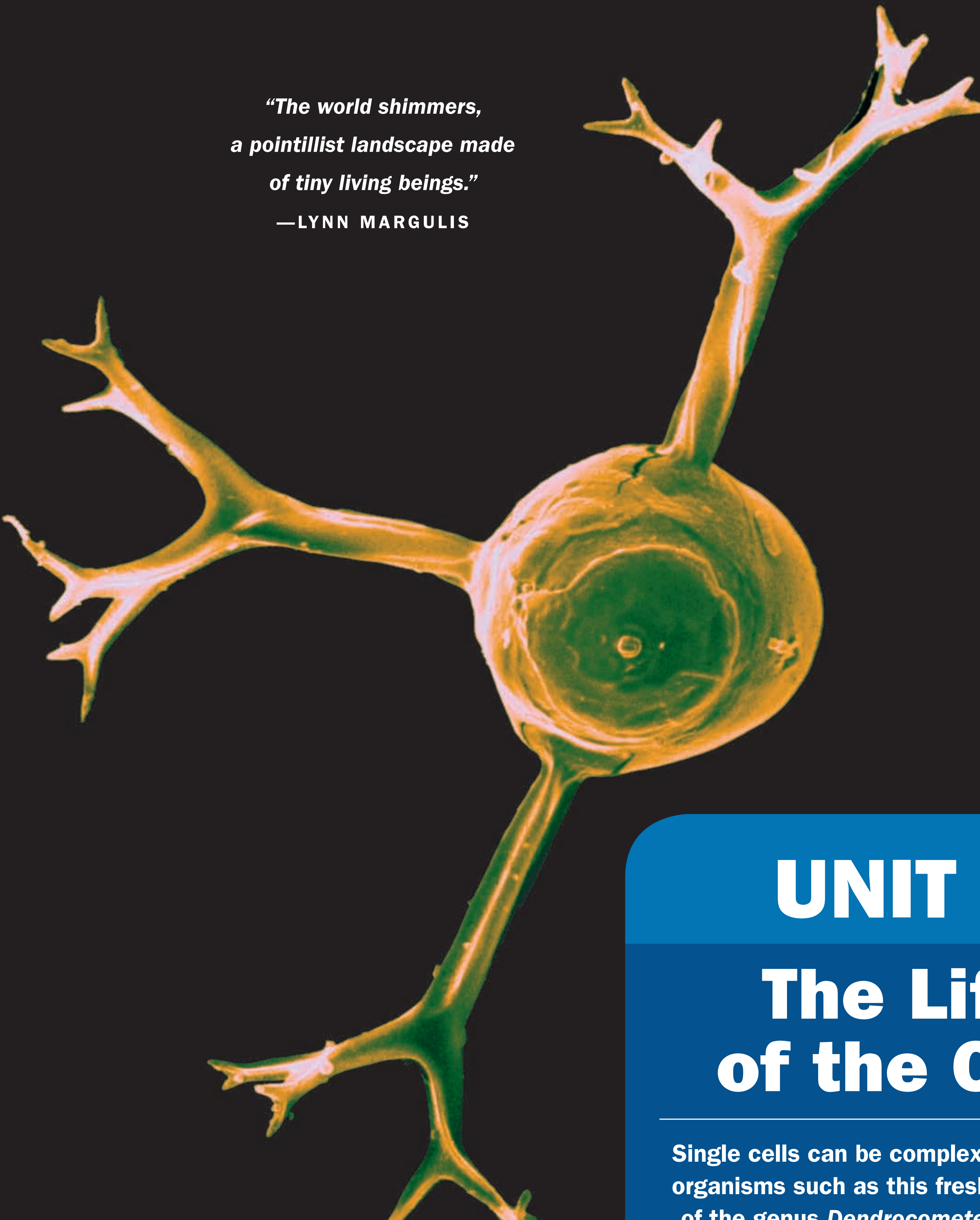
Applying the Concepts

Bloom's: Applying, Analyzing, Evaluating

1. What misunderstanding causes some people to dismiss evolution as "just a theory"?
2. How would this textbook's definition of life need to be changed to allow viruses to qualify as life-forms? For prions to be considered alive?
3. Review Alexander Fleming's experiment that led to the discovery of penicillin. What would be an appropriate control for the experiment in which Fleming applied filtered medium from a *Penicillium* culture to plates of bacteria?
4. Explain an instance in which your own understanding of a phenomenon enhances your appreciation of it.
5. In using the scientific method to help start your car, if jump-starting didn't work, what hypothesis would you test next?

*"The world shimmers,
a pointillist landscape made
of tiny living beings."*

—LYNN MARGULIS



UNIT 1

The Life of the Cell

Single cells can be complex, independent organisms such as this freshwater protist of the genus *Dendrocometes*. A rounded attachment region allows the cell to anchor firmly to the gills of freshwater fish or crustaceans. Tentacles, resembling microscopic antlers, snare food as water passes over them.

2 Atoms, Molecules, and Life

The aftermath of explosions at the Fukushima nuclear power plant in Japan.

CASE STUDY

Unstable Atoms Unleashed

ON MARCH 11, 2011, an earthquake of epic magnitude—9.0 on the Richter scale—shook the northeast coast of Japan. Soon after, a tsunami caused by the massive quake slammed into the Fukushima Daiichi nuclear power plant on Japan's eastern coast. Towering waves nearly 50 feet high flooded the plant and knocked out its main electrical power supply and backup generators, with disastrous consequences.

The core of a nuclear reactor, including the six that were at the Fukushima plant, contains thousands of fuel rods consisting of zirconium metal tubes filled with uranium fuel. Nuclear reactions in the core produce heat that converts water to steam that drives electricity-producing turbines. Each core is surrounded by two thick steel containment vessels. Water is pumped continuously around the vessels to absorb the intense heat generated by the nuclear reactions taking place inside them. This cooling system failed when the Fukushima plant lost power, and the temperature of the cores began to increase.

In a desperate attempt to cool the overheating cores, plant operators injected seawater into the inner containment vessels. But their efforts failed; the core temperature rose to over 1,800°F (about 1,000°C), melting the zirconium tubes and releasing radioactive fuel into the inner vessels. Stressed by the heat, the vessels cracked, allowing water and steam to escape. The steam reacted with the melted zirconium to generate hydrogen gas. As the pressure of the steam and hydrogen gas increased, it threatened to rupture the outer containment vessels.

In an attempt to prevent a rupture, plant operators vented the gas mixture—which also contained radioactive elements from the melted fuel rods—into the atmosphere. As the hot hydrogen gas encountered oxygen in the atmosphere, the two combined explosively, destroying parts of the buildings housing the containment vessels. Despite the venting, the outer containment vessels eventually gave way, unable to withstand the intense heat and pressure. Contaminated water flowed into the ocean from the compromised vessels for months following the disaster.

In the aftermath of the disaster, tens of thousands of people were evacuated from all habitations within 12 miles of the plant; the evacuees were not allowed to return until more than 6 years later. Even today, the melted core continues to generate contaminated water.

Why were people evacuated from their homes when radioactive gases were released into the atmosphere? How do the atoms of radioactive elements differ from those of nonradioactive elements?

AT A GLANCE

2.1 What Are Atoms?

2.2 How Do Atoms Interact to Form Molecules?

2.3 Why Is Water So Important to Life?

2.1 WHAT ARE ATOMS?

When you write "atom" with a pencil, the letters on the page are made of carbon. Now imagine cutting up that carbon into smaller and smaller particles, until all you have left is a pile of the smallest possible units of carbon: individual carbon atoms. A carbon atom is so small that 100 million of them placed in a row would span less than half an inch (1 centimeter).

Atoms Are the Basic Structural Units of Elements

Carbon is an example of an **element**—a substance that can neither be separated into simpler substances nor converted into a different substance by an ordinary **chemical reaction** (a process that forms or breaks bonds between atoms). Elements, alone or combined with other elements, form all matter. An **atom** is the smallest unit of an element, and each atom retains all the chemical properties of that element.

Ninety-two different elements occur in nature. Each is given an abbreviation, its *atomic symbol*. Most elements are present in only small quantities in the biosphere, and relatively few are essential to life on Earth. **TABLE 2-1** lists the elements most common in living things.

TABLE 2-1 Common Elements in Living Organisms

Element	Atomic Number[1]	Mass Number[2]	% by Weight in the Human Body
Oxygen (O)	8	16	65
Carbon (C)	6	12	18.5
Hydrogen (H)	1	1	9.5
Nitrogen (N)	7	14	3.0
Calcium (Ca)	20	40	1.5
Phosphorus (P)	15	31	1.0
Potassium (K)	19	39	0.35
Sulfur (S)	16	32	0.25
Sodium (Na)	11	23	0.15
Chlorine (Cl)	17	35	0.15
Magnesium (Mg)	12	24	0.05
Iron (Fe)	26	56	Trace
Fluorine (F)	9	19	Trace
Zinc (Zn)	30	65	Trace

[1]Atomic number: number of protons in the atomic nucleus.
[2]Mass number: total number of protons and neutrons.

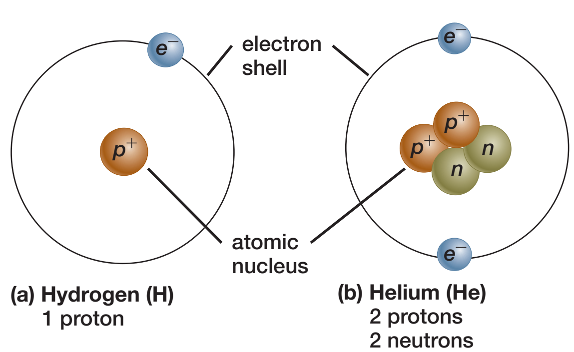
TABLE 2-2 Mass and Charge of Subatomic Particles

Subatomic Particle	Mass (in atomic mass units)	Charge
Neutron (*n*)	1	0
Proton (p^+)	1	+1
Electron (e^-)	0.00055	−1

Atoms Are Composed of Still Smaller Particles

Atoms are composed of *subatomic particles*: **neutrons** (*n*), which have no charge; **protons** (p^+), each of which carries a single positive charge; and **electrons** (e^-), each of which carries a single negative charge. An atom as a whole is uncharged, or *neutral*, because it contains equal numbers of protons and electrons, whose positive and negative charges electrically balance each other. The mass of a subatomic particle is measured in *atomic mass units*. As you can see in **TABLE 2-2**, each proton and neutron has a mass of 1 atomic mass unit, whereas an electron's mass is negligible compared to that of the larger particles. The total number of protons and neutrons in the nucleus of an atom is known as its **mass number**.

Protons and neutrons cluster together in the center of each atom, forming its **atomic nucleus**. An atom's tiny electrons are in continuous rapid motion around its nucleus within a defined three-dimensional space, as illustrated in **FIGURE 2-1**, which shows the two simplest atoms, hydrogen



▲ **FIGURE 2-1 Atomic models** Orbital models of **(a)** hydrogen (the only atom with no neutrons) and **(b)** helium. In these simplified models, the electrons (pale blue) are represented as miniature planets, orbiting around a nucleus that contains protons and neutrons.

THINK CRITICALLY What is the mass number of hydrogen? Of helium?

and helium. These *orbital models* of atomic structure are extremely simplified to make atoms easier to visualize. Atoms are never drawn to scale; if they were, and if this dot · were the nucleus, the electrons would be somewhere in the next room (or outside)—roughly 30 feet away.

Elements Are Defined by Their Atomic Numbers

The characteristic that defines each element, making it distinct from all others, is its **atomic number**—the number of protons in its nucleus. For example, a hydrogen atom has one proton, a carbon atom has six, and an oxygen atom has eight, giving these atoms atomic numbers of 1, 6, and 8, respectively. The **periodic table** in Appendix II organizes the elements according to their atomic numbers (rows) and their general chemical properties (columns).

Isotopes Are Atoms of an Element with Different Numbers of Neutrons

Although every atom of an element has the same number of protons, different atoms of an element may have different numbers of neutrons. Atoms of a given element with different numbers of neutrons are called **isotopes**. Each isotope of an element has a different mass number. An isotope's mass number is shown as a superscript preceding the atomic symbol.

Some Isotopes Are Radioactive

Most isotopes are stable; their nuclei do not change spontaneously. A few, however, are **radioactive**, meaning that their nuclei spontaneously break apart, or decay. Radioactive decay always emits energy and often emits subatomic particles as well. Radioactive decay of nuclei may convert an element to a different element. For example, nearly all carbon exists as stable ^{12}C. But a radioactive isotope called carbon-14 (^{14}C; 6 protons + 8 neutrons) is produced continuously by reactions in the atmosphere. When a radioactive ^{14}C molecule decays, energy is released and a neutron is converted to a proton, producing a stable nitrogen atom (^{14}N; 7 protons + 7 neutrons).

Radioactive Isotopes Are Important in Scientific Research and Medicine

Scientists often make use of radioactive isotopes. For example, archeologists can determine the age of artifacts because they know that after an organism dies, the ratio of ^{14}C to ^{12}C in its body declines at a predictable rate as the ^{14}C decays. By measuring this ratio in artifacts such as mummies, ancient trees, skeletons, or tools made of wood or bone, researchers can accurately assess the age of artifacts up to about 50,000 years old.

In laboratory research, scientists often insert radioactive isotopes into molecules within organisms. The radioactivity "labels" the molecules, making them easier to locate (and trace if they move). For example, experiments with radioactively labeled DNA and protein allowed scientists to conclude that DNA is the genetic material of cells (described in Chapter 12).

Modern medicine also makes extensive use of radioactive isotopes. For example, radiation therapy is frequently used to treat cancer. A radioactive isotope may be introduced into the bloodstream or implanted in the body near the cancer, or radiation may be directed into the tumor by an external device. Radiation damages DNA, so rapidly dividing cancer cells (which require intact DNA to divide) are particularly vulnerable. The radiation that kills cancer cells can also cause mutations in the DNA of healthy cells. These mutations slightly increase the chance that the patient will develop cancer again in the future, but most patients consider this a risk worth taking. For more information about uses for radioactive isotopes, see "Doing Science: Radioactive Revelations."

CASE STUDY CONTINUED

Unstable Atoms Unleashed

Because exposure to radioactivity can cause cancer, Japanese authorities have performed regular cancer screenings on hundreds of thousands of children exposed to radioactivity by the Fukushima power plant disaster. Fortunately, recent surveys have found no evidence of increased cancer rates.

But years after the meltdown, engineers at the Fukushima power plant—using remote-controlled robotic instruments—discovered hot spots of radiation so intense that a person exposed for an hour would be dead within a few weeks. Why would death come so fast? Extremely high doses of radiation damage DNA and other biological molecules so badly that cells can no longer function. Skin cells are destroyed. Cells lining the stomach and intestine break down, causing nausea and vomiting. Bone marrow, where blood cells and platelets are produced, is destroyed. The loss of white blood cells allows infections to flourish, and the loss of platelets crucial for blood clotting leads to internal bleeding.

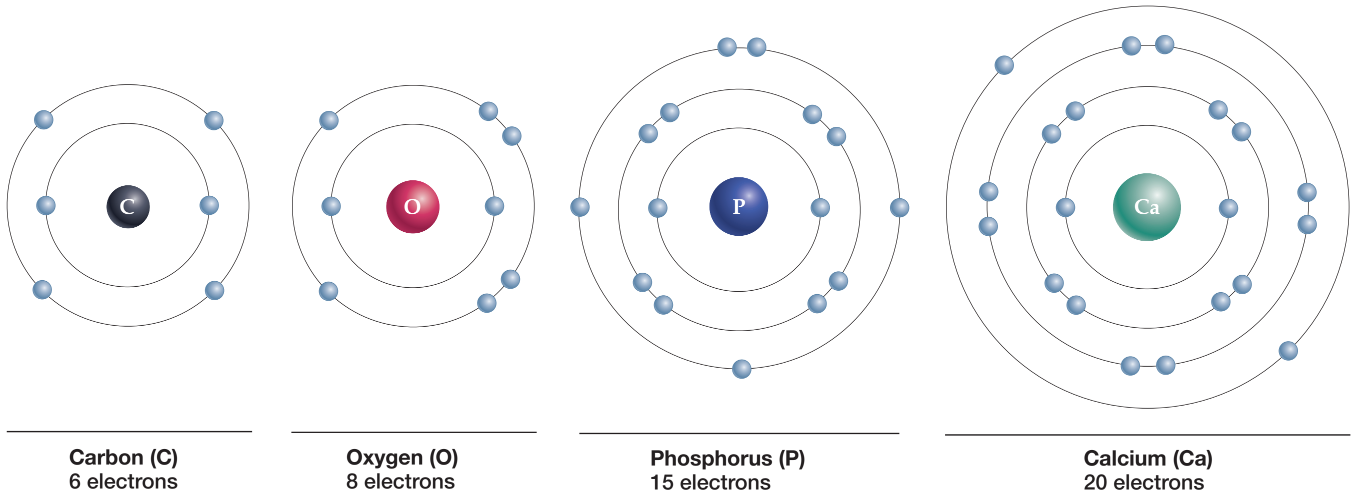
Fortunately, radioactive elements such as those released by the Fukushima disaster are rare in nature. Why do most elements remain stable?

Electrons Are Responsible for the Interactions Among Atoms

Nuclei and electrons play complementary roles in atoms. Nuclei (unless they are radioactive) provide stability; they remain unchanged during ordinary chemical reactions. Electrons, in contrast, are dynamic; they can capture and release energy, and as we describe later, they form the bonds that link atoms together into molecules.

Electrons Occupy Shells of Increasing Energy

Electrons occupy **electron shells**, complex three-dimensional regions around the nucleus. For simplicity, we will depict these shells as a series of increasingly large, concentric rings around



▲ **FIGURE 2-2 Electron shells in atoms** Most biologically important atoms have two or more shells of electrons. The shell closest to the nucleus can hold two electrons; the next three shells can each contain eight electrons.

THINK CRITICALLY Why do atoms with unfilled outer electron shells tend to react with one another?

the nucleus where electrons travel like planets orbiting the sun (**FIG. 2-2**). Each shell has a specific level of energy associated with it. The farther a shell extends from the nucleus, the greater the amount of energy stored in the electrons occupying the shell.

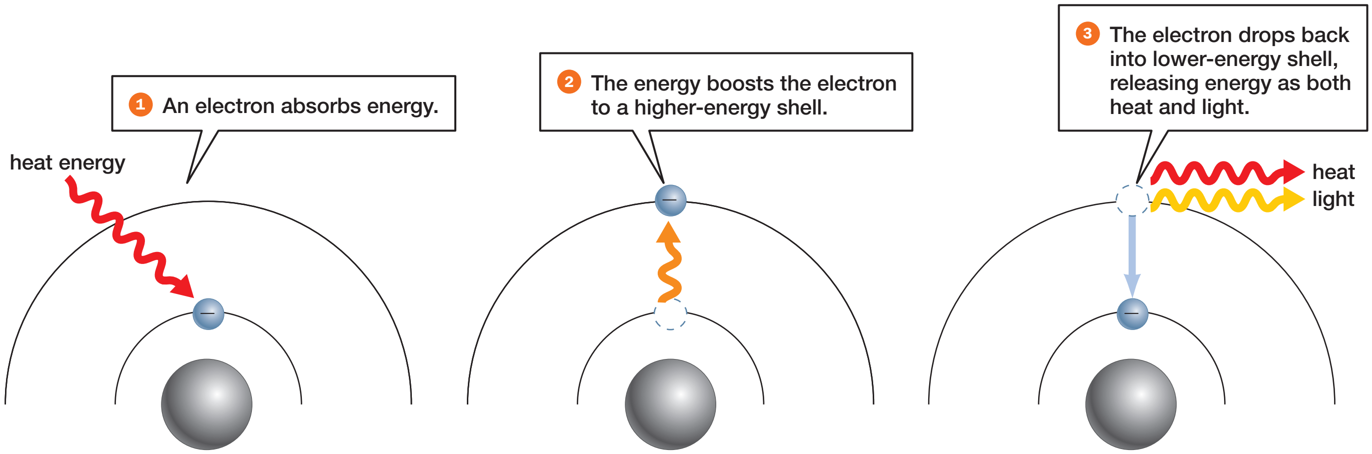
Electrons Can Capture and Release Energy

When an atom absorbs energy, the energy can cause an electron to jump from a lower-energy electron shell to a higher-energy shell. Soon afterward, the electron spontaneously falls back into its original electron shell and releases its extra energy as heat and often also as light (**FIG. 2-3**).

We make use of the ability of electrons to capture and release energy every time we switch on a light bulb. Although incandescent bulbs are rapidly becoming obsolete, they are the easiest type to understand. Electricity flows through a thin wire, heating it to around 4,500°F (about 2,500°C) for a 100-watt bulb. The heat energy bumps some electrons in the wire into higher-energy electron shells. As the electrons drop back down into their original shells, they emit some of the energy as light. Unfortunately, more than 90% of the energy absorbed by the wire is re-emitted as heat rather than light, making an incandescent bulb an extremely inefficient light source.

As Atomic Number Increases, Electrons Fill Shells Increasingly Distant from the Nucleus

Each electron shell can hold a specific number of electrons; the shell nearest the nucleus can hold only two, and more distant shells can hold eight or more. Electrons always fill the



▲ **FIGURE 2-3 Energy capture and release**

THINK CRITICALLY What causes the coals of a campfire to glow?

DOING Science Radioactive Revelations

Radioactivity plays a key role in imaging technologies that are widely used by researchers and physicians. One such technology is positron emission tomography (PET). To perform a PET scan, sugar molecules are tagged with a radioactive isotope and injected into a patient's bloodstream. The tagged molecules tend to move to the more metabolically active regions of the body, which require more sugar for energy. To discover where the radioactive isotope has accumulated, the patient's body is moved through a ring of detectors that respond to the energetic particles (positrons) emitted as the isotope decays. A powerful computer then uses these data to calculate precisely where the decays occurred and generates a color-coded map of the frequency of decays within each "slice" of body passing through the detector ring (**FIG. E2-1a**).

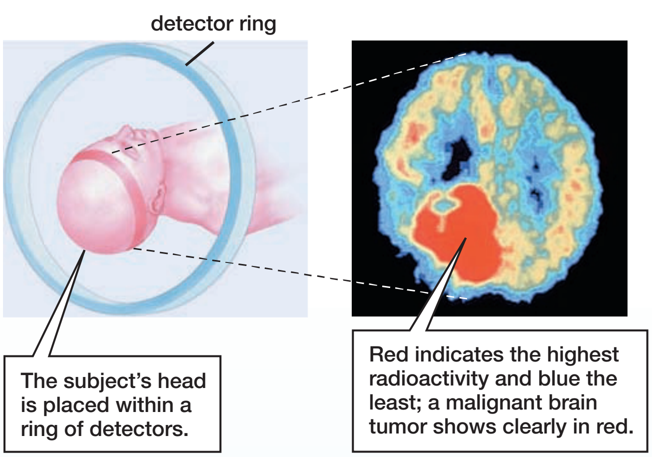
Among the uses of PET scans is medical diagnosis. A PET scan may reveal the location and size of a cancerous tumor or help determine if a patient has Alzheimer's disease. But how can physicians be confident that a PET scan will improve their diagnostic capabilities?

What Question Was Asked?

Can a PET brain scan reliably detect Alzheimer's disease and distinguish it from other causes of declining cognitive function? Before a diagnostic procedure can be widely adopted by physicians, its usefulness must be convincingly and repeatedly demonstrated by research. In one example of such research, investigators asked whether PET scans were any more effective than a physician's exam in identifying patients with Alzheimer's disease.

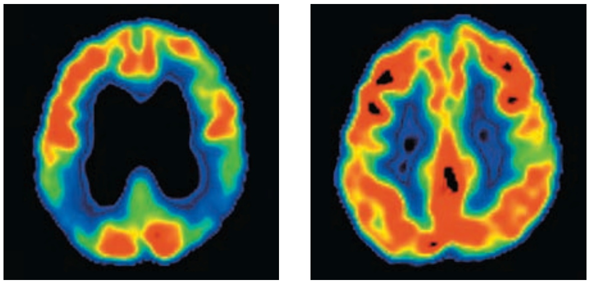
How Was Evidence Gathered?

To answer their question, the researchers focused on 45 people who had been examined by a medical team, had undergone a PET scan a few months after the exam, and were autopsied years later after death. About half of patients in the study had been diagnosed with Alzheimer's on the basis of the initial medical exam alone, and the other half had been judged Alzheimer's-free. The researchers then compared autopsy results (which confirm an Alzheimer's diagnosis with high reliability) with both the initial diagnosis by the medical team and a new diagnosis based on the PET scan. The researchers were careful to ensure that the diagnosticians analyzing the PET scans did not know the outcome of the autopsies.



(a) The subject is placed in a scanner **(b) The resulting computer image**

▲ **FIGURE E2-1 Positron emission tomography**



(a) Brain of patient with Alzheimer's **(b) Healthy brain**

▲ **FIGURE E2-2 PET reveals differences in brain function** Brain activity is rainbow color-coded, with red indicating the highest activity and blue the lowest; black areas are fluid-filled.

What Was Learned?

The results of the Alzheimer's diagnosis research showed that PET scans were more likely than physicians' exams to accurately diagnose Alzheimer's. This finding suggests that the effort and expense of a PET scan is worthwhile for patients who might have Alzheimer's. Subsequent PET scan research has identified subtle changes in brain activity that indicate very early stages of the disease, raising hope that early detection will help development of effective treatments.

PET scans provide effective diagnosis of Alzheimer's because the brain of a patient with Alzheimer's is far less active than that of a healthy individual (**FIG. E2-2**). In contrast, cancerous brain tumors show up in PET scans as "hot spots" of high activity, because their rapid cell division uses large amounts of sugar (**FIG. E2-1b**). In addition to its medical uses, PET is also used by researchers to learn which brain regions are active when a person performs a particular mental task, such as solving a math problem or recalling a past event.

THINK CRITICALLY In addition to lower brain activity, what other problem has occurred in the brain of the Alzheimer's patient as shown by the images in Fig. E2-2?