Concepts in Biology

Fourteenth Edition

Eldon D. Enger

Frederick C. Ross

David B. Bailey

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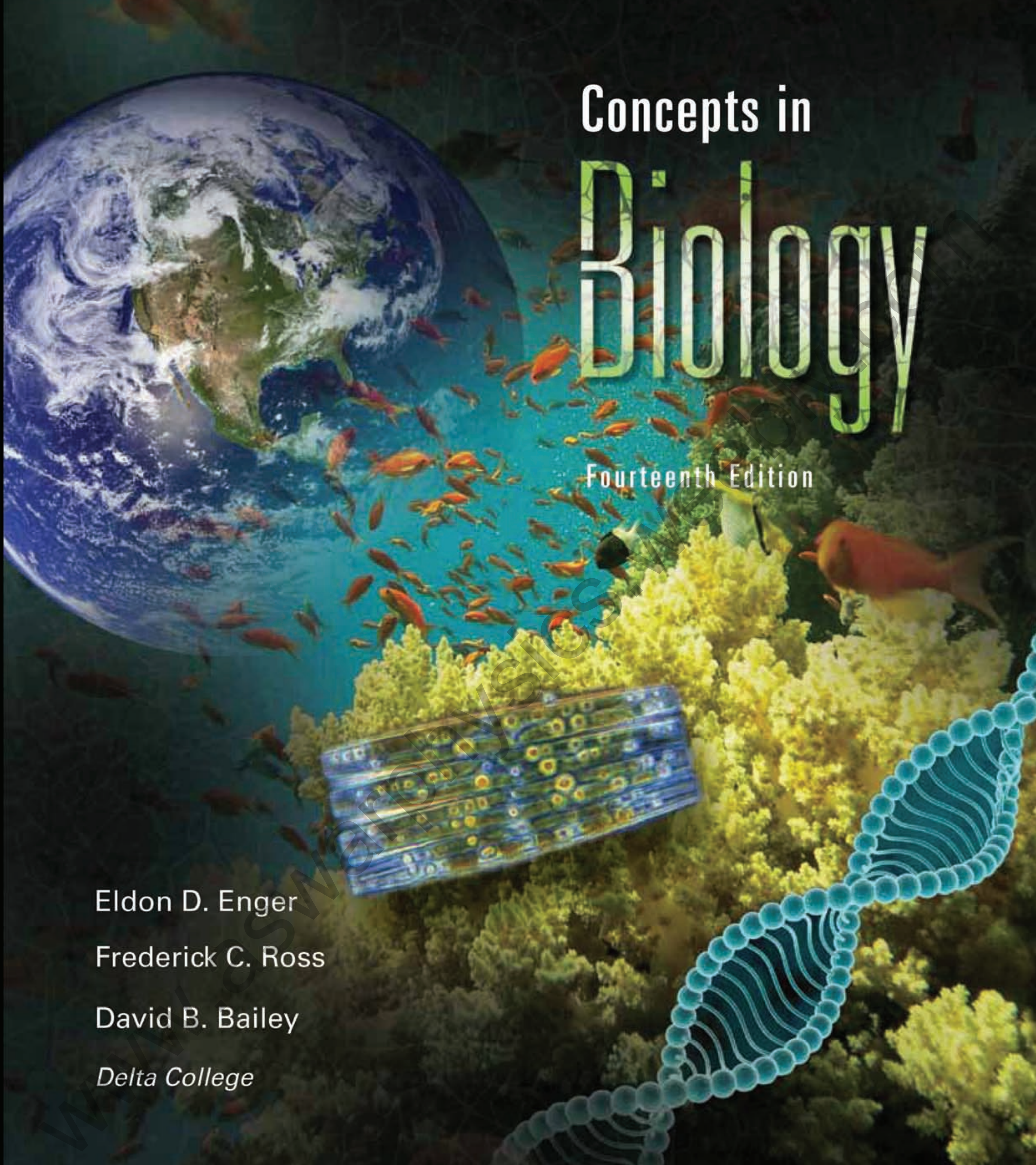

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Meet the Authors

Eldon D. Enger (Center)

Eldon D. Enger is a professor emeritus of biology at Delta College, a community college near Saginaw, Michigan. He received his B.A. and M.S. degrees from the University of Michigan. Professor Enger has over 30 years of teaching experience, during which he taught biology, zoology, environmental science, and several other courses, and he was very active in curriculum and course development. Professor Enger is an advocate for variety in teaching methodology. He feels that if students are provided with varied experiences, they are more likely to learn. In addition to the standard textbook assignments, lectures, and laboratory activities, his classes were likely to include writing assignments, student presentation of lecture material, debates by students on controversial issues, field experiences, individual student projects, and discussions of local examples and relevant current events.

Professor Enger has been a Fulbright Exchange Teacher to Australia and Scotland, and he received the Bergstein Award for Teaching Excellence and the Scholarly Achievement Award from Delta College.

Professor Enger is married, has two sons, and enjoys a variety of outdoor pursuits, such as cross-country skiing, hiking, hunting, fishing, camping, and gardening. Other interests include reading a wide variety of periodicals, beekeeping, singing in a church choir, and preserving garden produce.

Frederick C. Ross (Right)

Fred Ross is a professor emeritus of biology at Delta College, a community college near Saginaw, Michigan. He received his B.S. and M.S. from Wayne State University, Detroit, Michigan, and has attended several other universities and institutions. Professor Ross has over 30 years of teaching experience, including junior and senior high school. He has been very active in curriculum development and has developed the courses "Infection Control and Microbiology" and "AIDS and Infectious Diseases," a PBS ScienceLine course. He has also been actively involved in the National Task Force of Two Year College Biologists (American Institute of Biological Sciences); N.S.F. College Science Improvement Program (COSIP); Evaluator for Science and Engineering Fairs; Michigan Community College Biologists (MCCB); Judge for the Michigan Science Olympiad and the Science Bowl; and a member of the Topic Outlines in Introductory Microbiology Study Group of the American Society for Microbiology.

Professor Ross involved his students in a variety of learning techniques and was a prime advocate of writing-to-learn. Besides writing, his students were typically engaged in active learning techniques, including use of inquiry based learning, the Internet, e-mail communications, field experiences, classroom presentation, and lab work. The goal of his classroom presentations was to actively engage the minds of his students in understanding the material, not just memorization of "scientific facts."

David B. Bailey (Left)

David B. Bailey is an associate professor of biology at Delta College, a community college near Saginaw, Michigan. He received his B.A. from Hiram College, Hiram, Ohio, and his Ph.D. from Case Western Reserve University in Cleveland, Ohio. Dr. Bailey has been teaching in classrooms and labs for 10 years in both community colleges and 4-year institutions. He has taught general biology, introductory zoology, cell biology, molecular biology, biotechnology, genetics, and microbiology. Dr. Bailey is currently directing Delta's General Education Program.

Dr. Bailey strives to emphasize critical thinking skills so that students can learn from each other. Practicing the scientific method and participating in discussions of literature, religion, and movies, students are able to learn how to practice appropriate use of different critical thinking styles. Comparing different methods of critical thinking for each of these areas, students develop a much more rounded perspective on their world.

Dr. Bailey's community involvement includes participating with the Michigan Science Olympiad. In his spare time, he enjoys camping, swimming, beekeeping, and wine-making.

Brief Contents

Contents

Table of Boxes

Preface

The origin of this book remains deeply rooted in our concern for the education of college students in the field of biology. We believe that large, thick books intimidate introductory-level students who are already anxious about taking science courses. With each edition, we have worked hard to provide a book that is useful, interesting, and engaging to students while introducing them to the core concepts and current state of the science.

The Fourteenth Edition

There are several things about the fourteenth edition of *Concepts in Biology* that we find exciting. This revision, as with previous editions, is very much a collaborative effort. When we approach a revision, we carefully consider comments and criticisms of reviewers and discuss how to address their suggestions and concerns. As we proceed through the revision process, we solicit input from one another and we critique each other's work. This edition has several significant changes.

Opening Chapter Vignette

Nearly all of the chapter-opening vignettes are new. Each vignette is intended to draw the students into the chapter by showing how the material is relevant to their lives. To help meet this goal the vignettes have been redesigned to resemble a magazine layout to draw the attention of the reader.

Concept Review

In this edition, each major numbered heading ends with a Concept Review feature, which consists of a series of questions that probe the reader's level of understanding of the material in the section. The purpose of this feature is to encourage the reader to review the material in the section if he or she cannot answer the questions.

Enhanced Visuals and Page Layout

The visual elements of a text are extremely important to the learning process. Over 150 figures are new or have been modified. The purpose of these changes is to more clearly illustrate a concept or show examples of material discussed in the text.

Major Content Changes

Chapter 1 What Is Biology?

- Section 1.1, "Why the Study of Biology Is Important," and material in Section 1.2, "Cause-and-Effect Relationships," and "The Scientific Method" have been rewritten to better communicate these concepts.
- The material in Section 1.4 entitled "What Makes Something Alive?" has been reordered to present a more logical progression of ideas. Also in Section 1.4, "The Levels of Biological Organization and Emerging Properties" section has been rewritten and now includes the concept of emerging properties. In addition, "The Consequences of Not Understanding Biological Principles" has a new introduction designed to present the concept of selective acceptance of scientific evidence.

Chapter 2 The Basics of Life: Chemistry

- Section 2.1 "Matter, Energy, and Life" was rewritten to consolidate the introductory material on basic chemistry.

Chapter 3 Organic Molecules—The Molecules of Life

- New material in the section on proteins presents the concept of chaperone proteins.

Chapter 4 Cell Structure and Function

- There is a new section, "Basic Cell Types," that introduces the characteristics that are unique to eukaryotic and noneukaryotic cells. It also presents the most current thoughts on the evolution and relationships among the Bacteria, Archaea, and Eucarya.
- There is a new section on the two groups of membrane proteins involved in facilitated diffusion: (a) carrier proteins and (b) ion channels.
- A new diagram illustrates how all living things are classified.

Chapter 6 Biochemical Pathways—Cellular Respiration

- There are new summary presentations for each portion of cellular respiration, as suggested by reviewers' comments.

- There are several new figures and flow charts to enhance student understanding of these very complex pathways.

Chapter 7 Biochemical Pathways—Photosynthesis

- There are new summary presentations for each portion of photosynthesis suggested by reviewers' comments.
- There are several new figures and flow charts to enhance student understanding of these very complex pathways.

Chapter 8 DNA and RNA: The Molecular Basis of Heredity

- Sections 8.1, "DNA and the Importance of Proteins," and 8.2, "DNA Structure and Function," have been rewritten.
- There is a new section on epigenetics.
- Section 8.4, "Protein Synthesis," has been rewritten.
- There are new presentations on sickle cell anemia and other genetic abnormalities.

Chapter 9 Cell Division—Proliferation and Reproduction

- A new section on epigenetics and cancer was added.

Chapter 11 Applications of Biotechnology

- Information on genetically modified organisms has been extensively revised.

Chapter 14 The Formation of Species and Evolutionary Change

- New information is presented on Ida, *Darwinius masillae,* and her probable place in human evolution.
- Information on the proposed new species (hobbit) from Indonesia has been made current.
- A new table on primate classification has been added.
- There is a new section that discusses the recently published information about *Ardipithecus*.

Chapter 16 Community Interactions

- The material on the nature of biomes has been enhanced with additional photos and climographs to better illustrate the nature of each biome.
- A new section entitled "Modern Concepts of Succession and Climax" was added.

Chapter 17 Population Ecology

- The section on gene flow and gene frequency was reorganized.
- New material on the random and clumped distribution in populations was added to the text.

Chapter 19 The Origin of Life and the Evolution of Cells

- Section 19.3, "The 'Big Bang' and the Origin of the Earth," has new subheadings to help the reader follow the discussion.
- Section 19.4, "The Chemical Evolution of Life on Earth," was substantially reorganized and rewritten.
- Section 19.5, "Major Evolutionary Changes in Early Cellular Life," has had major sections rewritten.
- Table 19.1, "Summary of Characteristics of the Three Domains of Life," was rewritten and placed later in the chapter.
- Section 19.6, "The Geologic Timeline and the Evolution of Life," was rewritten to include new information, better sequencing of information, and more subheadings to aid the reader in following the discussion.

Chapter 20 The Classification and Evolution of Organisms

- The section on Archaea was substantially rewritten to include the latest information on the variety of kinds of Archaea found in oceans and soil.

Chapter 21 The Nature of Microorganisms

- Section 21.1, "What Are Microorganisms?" was substantially rewritten.
- The section on control of bacterial population now includes discussion of methicillin resistant *Staphylococcus*.
- The section on Archaea was substantially rewritten to include recent understanding of the nature of Archaea diversity.
- The section on Fungi has additional information on the classification of fungi and clarification on the meaning of yeast, mold, and mildew.

Chapter 23 The Animal Kingdom

- The section on body cavities was substantially rewritten.
- Section 23.6, "Primitive Marine Animals," was substantially rewritten.
- Section 23.10, "Mollusca," was substantially rewritten.
- The section on terrestrial arthropods was substantially rewritten.

Chapter 24 Materials Exchange in the Body

- The sections on white blood cells, platelets, and plasma were rewritten.

Chapter 25 Nutrition: Food and Diet

- Throughout the chapter when food calories are being discussed the term *Calorie* is used rather than *kilocalorie*.

- There has been a major reorganization of the material.
- The old section 25.7, "Deficiency Diseases," has been eliminated and much of the material in the section has been moved to parts of the chapter dealing with protein metabolism, vitamins, and minerals.
- Section 25.2, "Kinds of Nutrients and Their Function," has been reorganized with subheadings that highlight the nature and function of nutrients, how the body manages the nutrients, and other factors that are important to nutrition. Much new material was added.
- Tables 25.1, "Sources of Essential Amino Acids," 25.2, "Sources and Functions of Vitamins," and 25.3, "Sources and Functions of Minerals," have been updated and reorganized to help the reader see the significance of the nutrients.
- Material on discretionary Calories was added to the exercise portion of the Food Guide Pyramid discussion.
- The sections on body mass index and weight control were integrated into the section on obesity.
- Section 25.6, "Eating Disorders," has been completely rewritten.
- Section 25.8, "Nutrition for Sports and Fitness," has been substantially rewritten.

Chapter 26 The Body's Control Mechanisms and Immunity

- The section on negative and positive feedback was rewritten.
- Table 26.2 on inflammation was reorganized.
- Table 26.3 on classes of antibodies was reorganized.
- A new heading, "Immune System Diseases," now includes discussion of allergies, autoimmune diseases, and immunodeficiency diseases, which were previously discussed in different sections.

Chapter 27 Human Reproduction, Sex, and Sexuality

- A new section 27.2, "The Sexuality Spectrum," includes a reorganized discussion of intersexual anatomy, transsexual behavior, and homosexuality.
- A new section 27.3, "Components of Sexual Behavior," now discusses sexual attraction, foreplay, and intercourse.
- The section on contraception was significantly reorganized and rewritten.

Other Significant Changes

Thirty-seven new boxed readings have been added or substituted for boxed readings that had become dated:

HOW SCIENCE WORKS 2.2: Greenhouse Gases and Their Relationship to Global Warming

HOW SCIENCE WORKS 3.1: Organic Compounds: Poisons to Your Pets!

OUTLOOKS 3.2: So You Don't Eat Meat! How to Stay Healthy

OUTLOOKS 3.3: What Happens When You Deep-Fry Food?

HOW SCIENCE WORKS 4.2: Cell Membrane Structure and Tissue Transplants

HOW SCIENCE WORKS 5.1: Don't Be Inhibited—Keep Your Memory Alive

HOW SCIENCE WORKS 7.1: Solution to Global Energy Crisis Found in Photosynthesis?

HOW SCIENCE WORKS 8.1: Scientists Unraveling the Mystery of DNA

OUTLOOKS 8.1: Life in Reverse—Retroviruses

OUTLOOKS 8.3: One Small Change—One Big Difference!

HOW SCIENCE WORKS 9.1: The Concepts of Homeostasis and Mitosis Applied

OUTLOOKS 11.1: The First DNA Fingerprint in a Criminal Case

OUTLOOKS 12.1: Your Skin Color, Gene Frequency Changes, and Natural Selection

OUTLOOKS 13.2: Genetic Diversity and Health Care

OUTLOOKS 14.1: Evolution and Domesticated Cats

OUTLOOKS 15.1: Changes in the Food Chain of the Great Lakes

OUTLOOKS 15.2: Dead Zones

HOW SCIENCE WORKS 15.1: Scientists Accumulate Knowledge About Climate Change

HOW SCIENCE WORKS 16.1: Whole Ecosystem Experiments

OUTLOOKS 16.1: Varzea Forests—Seasonally Flooded Amazon Tropical Forests

OUTLOOKS 17.1: Marine Turtle Population Declines

HOW SCIENCE WORKS 18.1: Males Raised the Young in Some Species of Dinosaurs

HOW SCIENCE WORKS 19.1: The Oldest Rocks on Earth

HOW SCIENCE WORKS 20.1: New Information Causes Changes in Taxonomy and Phylogeny

OUTLOOKS 20.1: A Bacterium That Controls Animal Reproduction

HOW SCIENCE WORKS 21.1: How Many Microbes Are There?

OUTLOOKS 21.1: Food Poisoning/Foodborne Illness/Stomach Flu

OUTLOOKS 21.3: The Marine Microbial Food Web

HOW SCIENCE WORKS 22.1: Using Information from Tree Rings

OUTLOOKS 23.1: The Problem of Image

HOW SCIENCE WORKS 23.1: Genes, Development, and Evolution

OUTLOOKS 24.1: Blood Doping

OUTLOOKS 24.2: Newborn Jaundice

OUTLOOKS 25.3: Muscle Dysmorphia

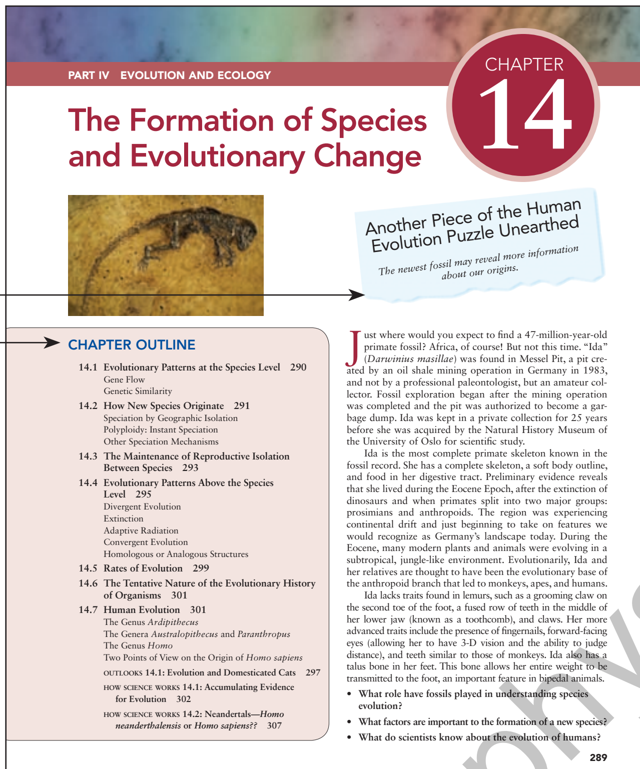
OUTLOOKS 25.5: Nutritional Health Products and Health Claims

OUTLOOKS 26.1: The Immune System and Transplants

OUTLOOKS 27.2: Causes of Infertility

Features

Opening Vignette The vignette is designed to pique students' interest and help them recognize the application and relevance of the topics presented in each chapter. The fourteenth edition also introduces bulleted questions for further reflections.



PART IV EVOLUTION AND ECOLOGY

CHAPTER 14

The Formation of Species and Evolutionary Change

Another Piece of the Human Evolution Puzzle Unearthed

The newest fossil may reveal more information about our origins.

CHAPTER OUTLINE

Just where would you expect to find a 47-million-year-old primate fossil? Africa, of course! But not this time. "Ida" (*Darwinius masillae*) was found in Messel Pit, a pit created by an oil shale mining operation in Germany in 1983, and not by a professional paleontologist, but an amateur collector. Fossil exploration began after the mining operation was completed and the pit was authorized to become a garbage dump. Ida was kept in a private collection for 25 years before she was acquired by the Natural History Museum of the University of Oslo for scientific study.

Ida is the most complete primate skeleton known in the fossil record. She has a complete skeleton, a soft body outline, and food in her digestive tract. Preliminary evidence reveals that she lived during the Eocene Epoch, after the extinction of dinosaurs and when primates split into two major groups: prosimians and anthropoids. The region was experiencing continental drift and just beginning to take on features we would recognize as Germany's landscape today. During the Eocene, many modern plants and animals were evolving in a subtropical, jungle-like environment. Evolutionarily, Ida and her relatives are thought to have been the evolutionary base of the anthropoid branch that led to monkeys, apes, and humans.

Ida lacks traits found in lemurs, such as a grooming claw on the second toe of the foot, a fused row of teeth in the middle of her lower jaw (known as a toothcomb), and claws. Her more advanced traits include the presence of fingernails, forward-facing eyes (allowing her to have 3-D vision and the ability to judge distance), and teeth similar to those of monkeys. Ida also has a talus bone in her feet. This bone allows her entire weight to be transmitted to the foot, an important feature in bipedal animals.

- **What role have fossils played in understanding species evolution?**
- **What factors are important to the formation of a new species?**
- **What do scientists know about the evolution of humans?**

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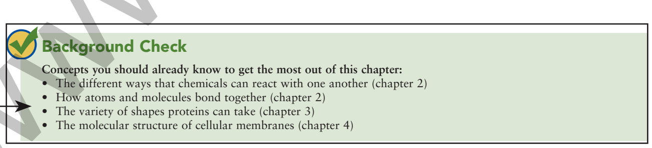
Chapter Outline At the opening of each chapter, the outline lists the major headings in the chapter, as well as the boxed readings.

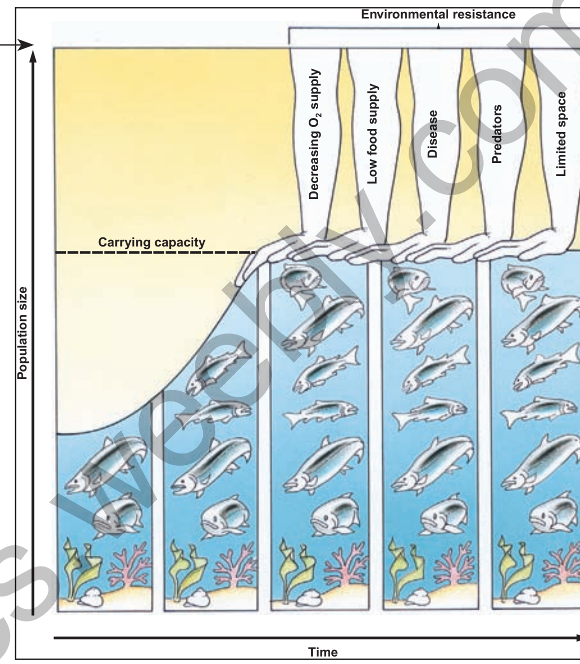
Background Check The Background Check lists the key concepts students should already understand to get the most out of the chapter. Chapter references are included for review purposes.



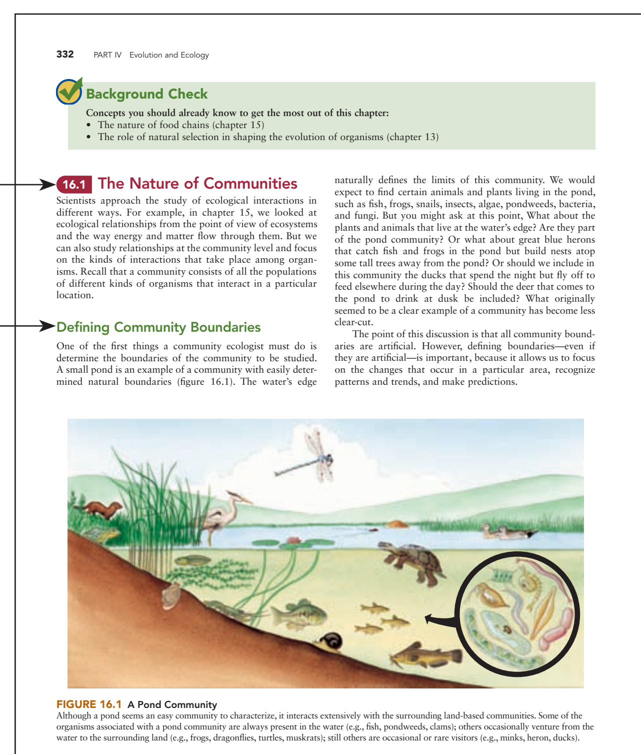
Background Check

Concepts you should already know to get the most out of this chapter:
- The different ways that chemicals can react with one another (chapter 2)
- How atoms and molecules bond together (chapter 2)
- The variety of shapes proteins can take (chapter 3)
- The molecular structure of cellular membranes (chapter 4)

Quality Visuals The line drawings and photographs illustrate concepts or associate new concepts with previously mastered information. Every illustration emphasizes a point or helps teach a concept.



Topical Headings Throughout each chapter, headings subdivide the material into meaningful sections that help readers recognize and organize information.



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Background Check

Concepts you should already know to get the most out of this chapter:
- The nature of food chains (chapter 15)
- The role of natural selection in shaping the evolution of organisms (chapter 13)

16.1 The Nature of Communities

Scientists approach the study of ecological interactions in different ways. For example, in chapter 15, we looked at ecological relationships from the point of view of ecosystems and the way energy and matter flow through them. But we can also study relationships at the community level and focus on the kinds of interactions that take place among organisms. Recall that a community consists of all the populations of different kinds of organisms that interact in a particular location.

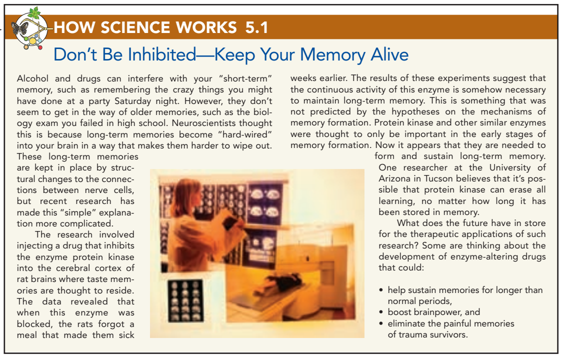
Defining Community Boundaries

One of the first things a community ecologist must do is determine the boundaries of the community to be studied. A small pond is an example of a community with easily determined natural boundaries (figure 16.1). The water's edge naturally defines the limits of this community. We would expect to find certain animals and plants living in the pond, such as fish, frogs, snails, insects, algae, pondweeds, bacteria, and fungi. But you might ask at this point, What about the plants and animals that live at the water's edge? Are they part of the pond community? Or what about great blue herons that catch fish and frogs in the pond but build nests atop some tall trees away from the pond? Or should we include in this community the ducks that spend the night but fly off to feed elsewhere during the day? Should the deer that comes to the pond to drink at dusk be included? What originally seemed to be a clear example of a community has become less clear-cut.

The point of this discussion is that all community boundaries are artificial. However, defining boundaries—even if they are artificial—is important, because it allows us to focus on the changes that occur in a particular area, recognize patterns and trends, and make predictions.

FIGURE 16.1 A Pond Community
Although a pond seems an easy community to characterize, it interacts extensively with the surrounding land-based communities. Some of the organisms associated with a pond community are always present in the water (e.g., fish, pondweeds, clams); others occasionally venture from the water to the surrounding land (e.g., frogs, dragonflies, turtles, muskrats); still others are occasional or rare visitors (e.g., minks, heron, ducks).

How Science Works and Outlooks Each of these boxed readings was designed to catch readers' interest by providing alternative views, historical perspectives, or interesting snippets of information related to the content of the chapter.


HOW SCIENCE WORKS 5.1

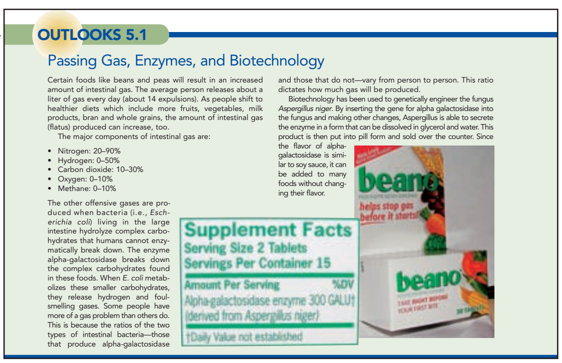
Don't Be Inhibited—Keep Your Memory Alive

Alcohol and drugs can interfere with your "short-term" memory, such as remembering the crazy things you might have done at a party Saturday night. However, they don't seem to get in the way of older memories, such as the biology exam you failed in high school. Neuroscientists thought this is because long-term memories become "hard-wired" into your brain in a way that makes them harder to wipe out. These long-term memories are kept in place by structural changes to the connections between nerve cells, but recent research has made this "simple" explanation more complicated.

The research involved injecting a drug that inhibits the enzyme protein kinase into the cerebral cortex of rat brains where taste memories are thought to reside. The data revealed that when this enzyme was blocked, the rats forgot a meal that made them sick weeks earlier. The results of these experiments suggest that the continuous activity of this enzyme is somehow necessary to maintain long-term memory. This is something that was not predicted by the hypotheses on the mechanisms of memory formation. Protein kinase and other similar enzymes were thought to only be important in the early stages of memory formation. Now it appears that they are needed to form and sustain long-term memory. One researcher at the University of Arizona in Tucson believes that it's possible that protein kinase can erase all learning, no matter how long it has been stored in memory.

What does the future have in store for the therapeutic applications of such research? Some are thinking about the development of enzyme-altering drugs that could:

- help sustain memories for longer than normal periods,
- boost brainpower, and
- eliminate the painful memories of trauma survivors.


OUTLOOKS 5.1

Passing Gas, Enzymes, and Biotechnology

Certain foods like beans and peas will result in an increased amount of intestinal gas. The average person releases about a liter of gas every day (about 14 expulsions). As people shift to healthier diets which include more fruits, vegetables, milk products, bran and whole grains, the amount of intestinal gas (flatus) produced can increase, too.

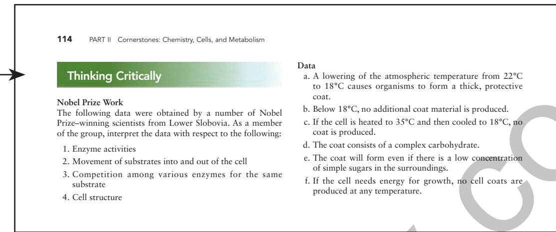
The major components of intestinal gas are:

- Nitrogen: 20–90%
- Hydrogen: 0–50%
- Carbon dioxide: 10–30%
- Oxygen: 0–10%
- Methane: 0–10%

The other offensive gases are produced when bacteria (i.e., *Escherichia coli*) living in the large intestine hydrolyze complex carbohydrates that humans cannot enzymatically break down. The enzyme alpha-galactosidase breaks down the complex carbohydrates found in these foods. When *E. coli* metabolizes these smaller carbohydrates, they release hydrogen and foul-smelling gases. Some people have more of a gas problem than others do. This is because the ratios of the two types of intestinal bacteria—those that produce alpha-galactosidase and those that do not—vary from person to person. This ratio dictates how much gas will be produced.

Biotechnology has been used to genetically engineer the fungus *Aspergillus niger*. By inserting the gene for alpha galactosidase into the fungus and making other changes, Aspergillus is able to secrete the enzyme in a form that can be dissolved in glycerol and water. This product is then put into pill form and sold over the counter. Since the flavor of alpha-galactosidase is similar to soy sauce, it can be added to many foods without changing their flavor.

Thinking Critically This feature gives students an opportunity to think through problems logically and arrive at conclusions based on the concepts presented in the chapters.


114 PART II Cornerstones: Chemistry, Cells, and Metabolism

Thinking Critically

Nobel Prize Work

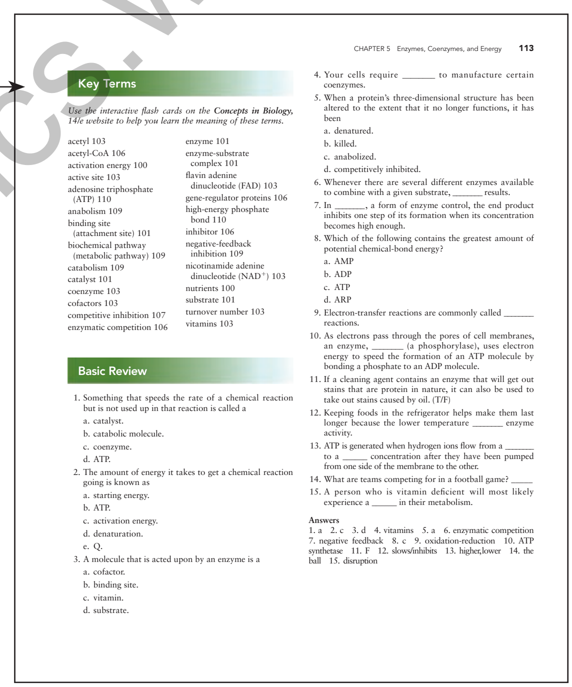
The following data were obtained by a number of Nobel Prize–winning scientists from Lower Slobovia. As a member of the group, interpret the data with respect to the following:

1. Enzyme activities
2. Movement of substrates into and out of the cell
3. Competition among various enzymes for the same substrate
4. Cell structure

Data

a. A lowering of the atmospheric temperature from 22°C to 18°C causes organisms to form a thick, protective coat.
b. Below 18°C, no additional coat material is produced.
c. If the cell is heated to 35°C and then cooled to 18°C, no coat is produced.
d. The coat consists of a complex carbohydrate.
e. The coat will form even if there is a low concentration of simple sugars in the surroundings.
f. If the cell needs energy for growth, no cell coats are produced at any temperature.

Page-Referenced Key Terms A list of page-referenced key terms in each chapter helps students identify the vocabulary they need to understand the concepts and ideas presented in the chapter. Definitions are found in the glossary at the end of the text. Students can practice learning key terms with interactive flash cards at www.mhhe.com/enger14e.


CHAPTER 5 Enzymes, Coenzymes, and Energy 113

Key Terms

*Use the interactive flash cards on the **Concepts in Biology**, 14/e website to help you learn the meaning of these terms.*

acetyl 103; acetyl-CoA 106; activation energy 100; active site 103; adenosine triphosphate (ATP) 110; anabolism 109; binding site (attachment site) 101; biochemical pathway (metabolic pathway) 109; catabolism 109; catalyst 101; coenzyme 103; cofactors 103; competitive inhibition 107; enzymatic competition 106; enzyme 101; enzyme-substrate complex 101; flavin adenine dinucleotide (FAD) 103; gene-regulator proteins 106; high-energy phosphate bond 110; inhibitor 106; negative-feedback inhibition 109; nicotinamide adenine dinucleotide (NAD^+) 103; nutrients 100; substrate 101; turnover number 103; vitamins 103

Basic Review

1. Something that speeds the rate of a chemical reaction but is not used up in that reaction is called a
   a. catalyst. b. catabolic molecule. c. coenzyme. d. ATP.
2. The amount of energy it takes to get a chemical reaction going is known as
   a. starting energy. b. ATP. c. activation energy. d. denaturation. e. Q.
3. A molecule that is acted upon by an enzyme is a
   a. cofactor. b. binding site. c. vitamin. d. substrate.
4. Your cells require ______ to manufacture certain coenzymes.
5. When a protein's three-dimensional structure has been altered to the extent that it no longer functions, it has been
   a. denatured. b. killed. c. anabolized. d. competitively inhibited.
6. Whenever there are several different enzymes available to combine with a given substrate, ______ results.
7. In ______, a form of enzyme control, the end product inhibits one step of its formation when its concentration becomes high enough.
8. Which of the following contains the greatest amount of potential chemical-bond energy?
   a. AMP b. ADP c. ATP d. ARP
9. Electron-transfer reactions are commonly called ______ reactions.
10. As electrons pass through the pores of cell membranes, an enzyme, ______ (a phosphorylase), uses electron energy to speed the formation of an ATP molecule by bonding a phosphate to an ADP molecule.
11. If a cleaning agent contains an enzyme that will get out stains that are protein in nature, it can also be used to take out stains caused by oil. (T/F)
12. Keeping foods in the refrigerator helps make them last longer because the lower temperature ______ enzyme activity.
13. ATP is generated when hydrogen ions flow from a ______ to a ______ concentration after they have been pumped from one side of the membrane to the other.
14. What are teams competing for in a football game? ______
15. A person who is vitamin deficient will most likely experience a ______ in their metabolism.

Answers

1. a 2. c 3. d 4. vitamins 5. a 6. enzymatic competition 7. negative feedback 8. c 9. oxidation-reduction 10. ATP synthetase 11. F 12. slows/inhibits 13. higher, lower 14. the ball 15. disruption

Chapter Summary The summary at the end of each chapter clearly reviews the concepts presented.

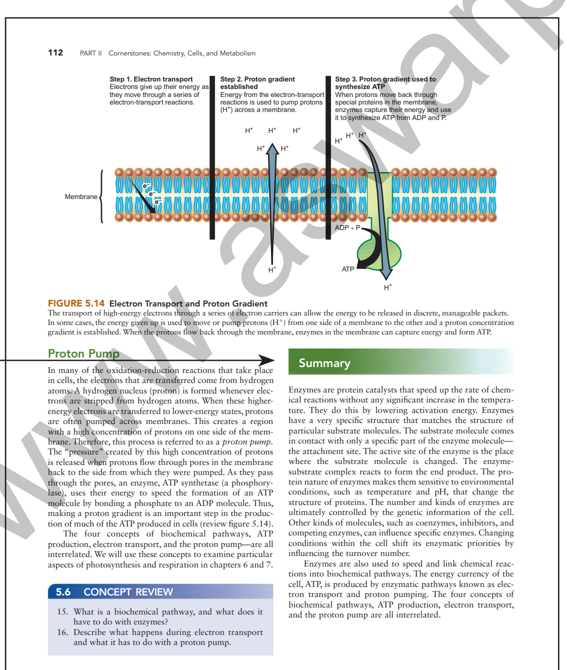

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FIGURE 5.14 Electron Transport and Proton Gradient

The transport of high-energy electrons through a series of electron carriers can allow the energy to be released in discrete, manageable packets. In some cases, the energy given up is used to move or pump protons (H^+) from one side of a membrane to the other and a proton concentration gradient is established. When the protons flow back through the membrane, enzymes in the membrane can capture energy and form ATP.

Proton Pump

In many of the oxidation-reduction reactions that take place in cells, the electrons that are transferred come from hydrogen atoms. A hydrogen nucleus (proton) is formed whenever electrons are stripped from hydrogen atoms. When these higher-energy electrons are transferred to lower-energy states, protons are often pumped across membranes. This creates a region with a high concentration of protons on one side of the membrane. Therefore, this process is referred to as a *proton pump*. The "pressure" created by this high concentration of protons is released when protons flow through pores in the membrane back to the side from which they were pumped. As they pass through the pores, an enzyme, ATP synthetase (a phosphorylase), uses their energy to speed the formation of an ATP molecule by bonding a phosphate to an ADP molecule. Thus, making a proton gradient is an important step in the production of much of the ATP produced in cells (review figure 5.14).

The four concepts of biochemical pathways, ATP production, electron transport, and the proton pump—are all interrelated. We will use these concepts to examine particular aspects of photosynthesis and respiration in chapters 6 and 7.

5.6 CONCEPT REVIEW

15. What is a biochemical pathway, and what does it have to do with enzymes?
16. Describe what happens during electron transport and what it has to do with a proton pump.

Summary

Enzymes are protein catalysts that speed up the rate of chemical reactions without any significant increase in the temperature. They do this by lowering activation energy. Enzymes have a very specific structure that matches the structure of particular substrate molecules. The substrate molecule comes in contact with only a specific part of the enzyme molecule—the attachment site. The active site of the enzyme is the place where the substrate molecule is changed. The enzyme-substrate complex reacts to form the end product. The protein nature of enzymes makes them sensitive to environmental conditions, such as temperature and pH, that change the structure of proteins. The number and kinds of enzymes are ultimately controlled by the genetic information of the cell. Other kinds of molecules, such as coenzymes, inhibitors, and competing enzymes, can influence specific enzymes. Changing conditions within the cell shift its enzymatic priorities by influencing the turnover number.

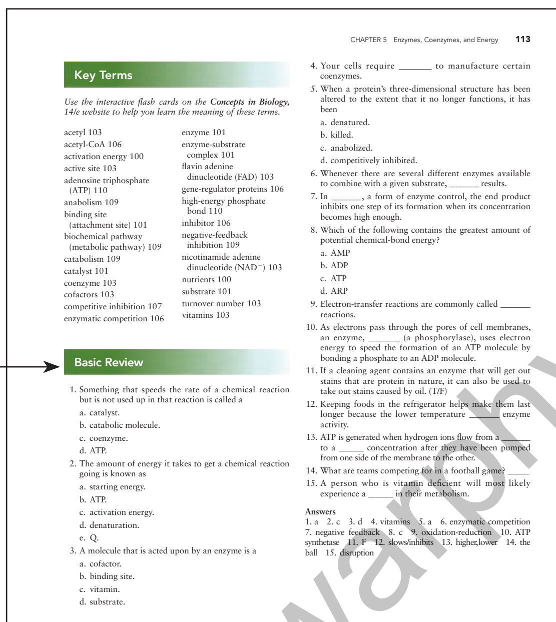
Enzymes are also used to speed and link chemical reactions into biochemical pathways. The energy currency of the cell, ATP, is produced by enzymatic pathways known as electron transport and proton pumping. The four concepts of biochemical pathways, ATP production, electron transport, and the proton pump are all interrelated.

Concept Review Questions At the end of each numbered section of the text there are review questions that help students assess their understanding of the material. Concept review questions are answered at www.mhhe.com/enger14e.

5.1 CONCEPT REVIEW

1. What is the difference between a catalyst and an enzyme?
2. How do enzymes increase the rate of a chemical reaction?

Basic Review Questions Students can assess their knowledge by answering the basic review questions. The answers to the basic review questions are given at the end of the question set so students can get immediate feedback.


CHAPTER 5 Enzymes, Coenzymes, and Energy 113

Key Terms

Use the interactive flash cards on the ***Concepts in Biology, 14/e*** *website to help you learn the meaning of these terms.*

acetyl 103
acetyl-CoA 106
activation energy 100
active site 103
adenosine triphosphate (ATP) 110
anabolism 109
binding site (attachment site) 101
biochemical pathway (metabolic pathway) 109
catabolism 109
catalyst 101
coenzyme 103
cofactors 103
competitive inhibition 107
enzymatic competition 106
enzyme 101
enzyme-substrate complex 101
flavin adenine dinucleotide (FAD) 103
gene-regulator proteins 106
high-energy phosphate bond 110
inhibitor 106
negative-feedback inhibition 109
nicotinamide adenine dinucleotide (NAD^+) 103
nutrients 100
substrate 101
turnover number 103
vitamins 103

Basic Review

1. Something that speeds the rate of a chemical reaction but is not used up in that reaction is called a
   a. catalyst.
   b. catabolic molecule.
   c. coenzyme.
   d. ATP.
2. The amount of energy it takes to get a chemical reaction going is known as
   a. starting energy.
   b. ATP.
   c. activation energy.
   d. denaturation.
   e. Q.
3. A molecule that is acted upon by an enzyme is a
   a. cofactor.
   b. binding site.
   c. vitamin.
   d. substrate.
4. Your cells require _______ to manufacture certain coenzymes.
5. When a protein's three-dimensional structure has been altered to the extent that it no longer functions, it has been
   a. denatured.
   b. killed.
   c. anabolized.
   d. competitively inhibited.
6. Whenever there are several different enzymes available to combine with a given substrate, _______ results.
7. In _______, a form of enzyme control, the end product inhibits one step of its formation when its concentration becomes high enough.
8. Which of the following contains the greatest amount of potential chemical-bond energy?
   a. AMP
   b. ADP
   c. ATP
   d. ARP
9. Electron-transfer reactions are commonly called _______ reactions.
10. As electrons pass through the pores of cell membranes, an enzyme, _______ (a phosphorylase), uses electron energy to speed the formation of an ATP molecule by bonding a phosphate to an ADP molecule.
11. If a cleaning agent contains an enzyme that will get out stains that are protein in nature, it can also be used to take out stains caused by oil. (T/F)
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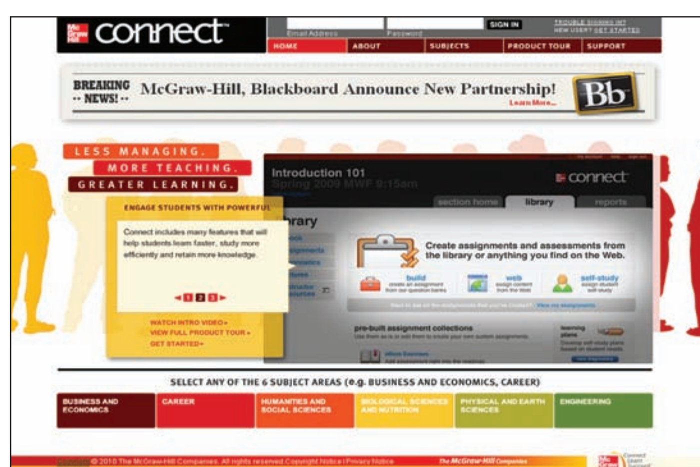

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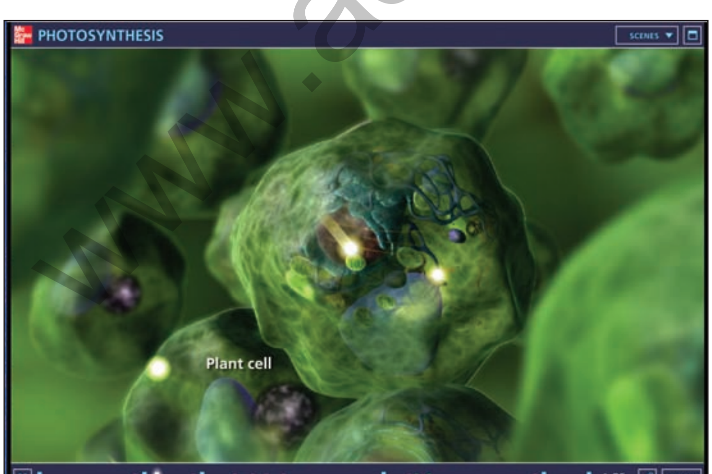

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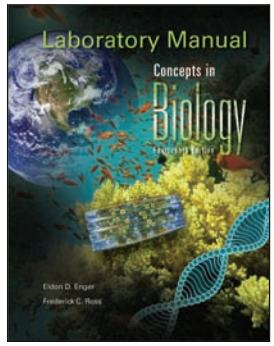
Instructor's Manual

The Instructor's manual contains an overview and a list of goals and objectives for each chapter.

Laboratory Manual



The laboratory manual features 30 carefully designed, class-tested learning activities. Each exercise contains an introduction to the material, step-by-step procedures, ample space to record and graph data, and review questions. The activities give students an opportunity to go beyond reading and studying to actually participate in the process of science.

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- Animations
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CHAPTER 1

What Is Biology?

Foodborne Illness on the Rise

As Population Increases So Does Concern for Food Safety.

CHAPTER OUTLINE

More than ever before, people around the world are worried about the safety of their food. Foodborne illnesses are diseases caused by infectious microbes (germs) or poisons that enter your body if you eat contaminated food. They result in sickness or death. The chemical contamination of baby formula made in China in 2008 was responsible for at least four infant deaths and over 53,000 illnesses. Everybody is at risk of foodborne illness. In fact, World Health Organization (WHO) scientists have stated that foodborne illnesses have become major problems in both developed and developing countries. Meats, vegetables, salads, snacks, fast food, vegetarian snacks, and even desserts have been found to be sources of foodborne illness. It is the variety of outbreaks that most troubles scientists and government health officials who are responsible for investigating and making recommendations for controlling outbreaks. WHO reported that the global incidence of death from diarrheal diseases caused by foodborne disease was 1.8 million. Diarrhea is a major cause of malnutrition in infants and young children. In the United States of America (USA), there are an estimated 76 million cases of foodborne diseases each year. These result in about 325,000 hospitalizations and 5,000 deaths. Food contamination has huge social and economic consequences on communities and their healthcare systems.

- **How would a scientist approach the claim that the increase in foodborne illness is the result of a greater interest by consumers in eating fresh, uncooked foods?**
- **How would scientists go about identifying the cause of a foodborne illness?**
- **Should supersized food-processing companies be split into smaller, more easily regulated businesses?**

Background Check

Concepts you should already know to get the most out of this chapter:
At the beginning of each chapter, you will find a list of concepts or ideas that are helpful in understanding the content of the chapter. Since this is the first chapter, there is no special background required. However, you should:
- Have an open mind
- Be willing to learn

1.1 Why the Study of Biology Is Important

Many students question the need for science courses, such as biology, especially when their area of study is not science-related. However, it is becoming increasingly important for everyone to be able to recognize the power and limitations of science. In a democracy, it is assumed that the public has gathered enough information to make intelligent decisions. This is why an understanding of the nature of science and fundamental biological concepts is so important for any person, regardless of his or her occupation. *Concepts in Biology* was written with this philosophy in mind. This book presents core concepts selected to help you become more aware of how biology influences nearly every aspect of your life.

Most of the important questions of today can be considered from philosophical, scientific, and social points of view. However, none of these approaches individually answers those questions. For example, it is a fact that the human population of the world is growing rapidly. Philosophically, we may all agree that the rate of population growth should be slowed. Science can provide information about how populations grow and which actions will be the most effective in slowing population growth. Science can also develop effective methods of birth control. Social leaders can suggest strategies for population control that are acceptable within a society. It is important to recognize that science does not have the answers to all of our problems. In this situation, society must make the fundamental philosophical decisions about reproductive rights and the morality of various control methods if human population growth is to be controlled.

While science may raise many questions that are difficult for society to answer, science can challenge humanity to re-examine long-held beliefs. As science reports facts and trends, this new information can force us to rethink our view of the world. One example of this is the idea of human race. Only recently have we been able to look at all the genetic information that makes up a human. Now, it is possible to determine the genetic differences between different races of humans. Interestingly, the genetic differences between individual people of the same race can be greater than the differences among individuals who were thought to be of different races. The reason for this is that the number of genes that we typically associate with racial differences is very small when compared to the number of genes needed to make a person (figure 1.1).

FIGURE 1.1 What's the Difference?
Despite superficial differences, different human races are overwhelmingly similar genetically.

Consider how this new information challenges the human perception of race. Humans define country borders and fight wars on the basis of race. This is true even though what makes up genetic differences between races is inconsequential to what makes us human.

1.1 CONCEPT REVIEW

1. Why is a basic understanding of science important for all citizens?
2. Describe two areas where scientific discoveries have caused us to rethink previously held beliefs.

1.2 Science and the Scientific Method

Most textbooks define **biology** as the science that deals with life. This definition seems clear until you begin to think about what the words *science* and *life* mean.

Science is actually a *process* used to solve problems or develop an understanding of repetitive natural events that involves the accumulation of knowledge and the testing of possible answers. The process has become known as the *scientific method*. The **scientific method** is a way of gaining information (facts) about the world by forming possible answers to questions, followed by rigorous testing to determine if the proposed explanations are supported by the facts.

Basic Assumptions in Science

When using the scientific method, scientists make some basic assumptions:

- There are specific causes for naturally reoccurring events observed in the natural world.
- The causes for events in nature can be identified.
- There are general rules or principles that can be used to describe what happens in nature.
- An event that occurs repeatedly probably has the same cause each time it occurs.
- What one person observes can be observed by others.
- The same fundamental rules of nature apply, regardless of where and when they occur.

For example, we have all observed lightning with thunderstorms. According to the assumptions that have just been stated, we should expect that there is a cause of all cases of lightning, regardless of where or when they occur, and that all people could make the same observations. We know from scientific observations and experiments that

(1) lightning is caused by a difference in electrical charge,
(2) the behavior of lightning follows the same general rules as those for static electricity, and
(3) all lightning that has been measured has had the same cause wherever and whenever it has occurred regardless of who made the observation.

Cause-and-Effect Relationships

Scientists distinguish between situations that are merely correlated (happen together) and those that are correlated and show *cause-and-effect relationships*. Many events are correlated, but not all correlations show cause-and-effect. When an event occurs as a direct result of a previous event, a cause-and-effect relationship exists. For example, lightning and thunder are correlated and have a cause-and-effect relationship. Lightning causes thunder.

The relationship between ingesting microorganisms and foodborne illness can be difficult to figure out. Because people have experienced bacterial, viral, or fungal infections, many assume that all microbes cause disease. In addition, the media portray all microbes as dangerous. Companies tell us that you should buy their antimicrobial product. They claim that their product will kill all the microbes, and therefore you will not come down with a foodborne illness. However, scores of different scientists have demonstrated through countless laboratory experiments that only a small number of microbes are *pathogenic*; that is, capable of causing harm. In fact, it turns out that most microbes are beneficial. These experiments have led to the identification of specific mechanisms by which pathogens cause harm. For example, a specific toxin (poison) can be collected from a suspect bacterium, purified, and administered to a laboratory animal in its food. If the animal displays the predicted foodborne illness symptoms, the experiment lends credibility to the fact that the microbe is responsible for that illness. Knowing that a cause-and-effect relationship exists enables us to make a prediction. If the same set of circumstances occurs in the future, the same effect will result.

The Scientific Method

The term *scientifically* is used in commercials, "science" programs on TV, public meetings, and in many other situations. Is this term being used correctly? In most cases the answer is "no!" In most of these situations, the term *scientifically* is used to mean "precisely," or with great accuracy. Science is a method that requires setting up a control group to which the experimental group is compared.

The scientific method involves an orderly, careful search for information. The method involves a continual checking and rechecking to see if previous conclusions are still supported by new evidence. If new evidence is not supportive, scientists discard or change their original ideas. Thus, scientific ideas undergo constant reevaluation, criticism, and modification as new discoveries are made. This can be very bewildering to the general public and can lead to people making comments such as, "Can't they make up their minds?" or "That's not what they said the last time." The scientific method has several important components:

- Careful observation
- The construction and testing of hypotheses
- An openness to new information and ideas
- A willingness to submit one's ideas to the scrutiny of others

The purpose of this method is to help scientists avoid making faulty assumptions and false claims. It is closely tied to the assumptions listed earlier and consists of several widely accepted steps (figure 1.2). However, scientists do not typically follow these steps from the first step (observation) to the last (communication). They take advantage of the work done by others and jump in and out of this series at various places.

Observation

Scientific inquiry begins with an observation. We make an **observation** when we use our senses (i.e., smell, sight, hearing, taste, touch) or an extension of our senses (e.g., microscope, sound recorder, X-ray machine, thermometer) to record an event.

However, there is a difference between a scientific observation and simple awareness. For example, you might hear a sound or see something without really observing it. You have probably seen a magician, an illusionist, or a mystic perform tricks, but do you really know what's going on 'behind the

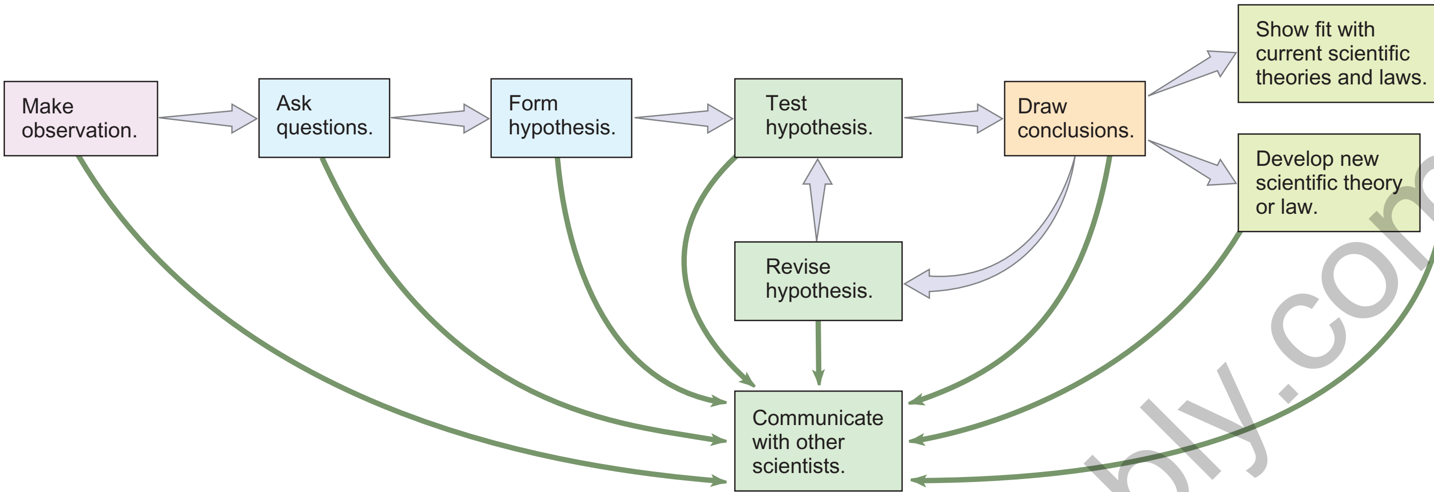


FIGURE 1.2 The Scientific Method
The scientific method is a way of thinking that involves making hypotheses about observations and testing the validity of the hypotheses. When hypotheses are disproved, they are revised and tested in their new form. Throughout the scientific process, people communicate their ideas. Scientific theories and laws develop as a result of people recognizing broad areas of agreement about how the world works. These laws and theories help people develop their approaches to scientific questions.

(a) (b)

FIGURE 1.3 Observation
Careful observation is an important part of the scientific method. *(a)* This technician is making observations on the characteristics of soil and recording the results. *(b)* What is really going on here? What are you not observing?

scenes'? (figure 1.3) When scientists talk about their observations, they are referring to careful, thoughtful recognition of an event—not just casual notice. Scientists train themselves to improve their observational skills, because careful observation is important in all parts of the scientific method.

Questioning and Exploration

As scientists make observations, they begin to develop *questions*. How does this happen? What causes it to occur? When will it take place again? Can I control the event to my benefit? Forming questions is not as simple as it might seem, because the way you ask questions determines how you answer them. A question that is too broad or too complex may be impossible to answer; therefore, a great deal of effort is put into asking the question in the right way. In some situations, this is the most time-consuming part of the scientific method; asking the right question is critical to how you look for answers.

Let's say that you have observed a cat catch, kill, and eat a mouse. You could ask several kinds of questions:

1a. What motivates a cat to hunt?	1b. Do cats hunt more when they are hungry?
2a. Why did the cat kill the mouse?	2b. Is the killing behavior of the cat instinctive or learned?
3a. Did the cat like the taste of the mouse?	3b. If given a choice between mice and canned cat food, which would cats choose?

Although questions 1a, 2a, and 3a are good questions, it would be very difficult to design an experiment to evaluate them. On the other hand questions 1b, 2b, and 3b lend themselves to experiment. The behavior of hungry and recently fed cats could be compared. The behavior of mature cats that have not had an opportunity to interact with live mice could be compared to that of mature cats who had accompanied their mothers as they hunted and killed mice. Cats could be offered a choice between a mouse and canned cat food and their choices could be recorded (figure 1.4).

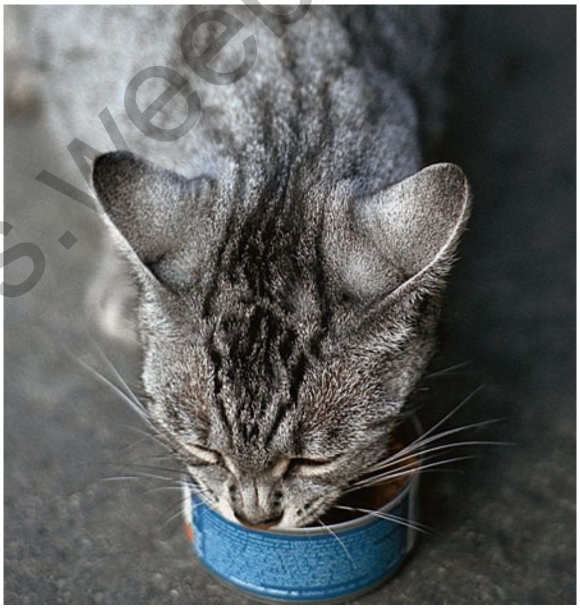
Once a decision has been made about what question to ask, scientists *explore other sources of knowledge* to gain more information. Perhaps the question has already been answered by someone else. Perhaps several possible answers have already been rejected. Knowing what others have already done can save time and energy. This process usually involves reading appropriate science publications, exploring information on the Internet, and contacting fellow scientists interested in the same field of study. After exploring these sources of information, a decision is made about whether to continue to consider the question. If the scientist is still intrigued by the question, he or she constructs a formal hypothesis and continues the process of inquiry at a different level.

Constructing Hypotheses

A **hypothesis** is a statement that provides a possible answer to a question or an explanation for an observation that can be tested. A good hypothesis must have the following characteristics:

(1) It must be logical.
(2) It must account for all the relevant information currently available.
(3) It must allow one to predict future events relating to the question being asked.
(4) It must be testable.

Do cats hunt more when they are hungry?



If given a choice between mice and cat food, which would cats choose?

FIGURE 1.4 Questioning
The scientific method involves forming questions about what you observe.

(5) Furthermore, if one has a choice of several hypotheses, one should use the simplest one with the fewest assumptions.

Just as deciding which questions to ask is often difficult, forming a hypothesis requires much critical thought and mental exploration.

Testing Hypotheses

Scientists test a hypothesis to see if it is supported or disproved. If they disprove the hypothesis, they reject it and must construct a new hypothesis. However, if they cannot disprove a hypothesis, they are more confident in the *validity* (able to be justified; on target) of the hypothesis, even though they have not proven it true in all cases and for all time. Science always allows for the questioning of ideas and the substitution of new explanations as new information is obtained. As new information is obtained, an alternative hypothesis may become apparent and may explain the situation better than the original hypothesis. It is also possible, however, that the scientists have not made the appropriate observations to indicate that the hypothesis is wrong.

The test of a hypothesis can take several forms.

(1) Collecting relevant information

In some cases collecting relevant information that already exists may be an adequate test of a hypothesis. For example, suppose you visited a cemetery and observed, from reading the tombstones, that an unusually large number of people of various ages died in the same year. You could hypothesize that an epidemic of disease or a natural disaster caused the deaths. To test this hypothesis, you could consult historical newspaper accounts for that year.

(2) Making additional observations

Often making additional observations may be all that is necessary to test a hypothesis. For example, suppose you hypothesized that a certain species of bird uses holes in trees as places to build nests. You could observe several birds of the species and record the kinds of nests they build and where they build them.

(3) Devising an experiment

A common method for testing a hypothesis involves devising an experiment. An **experiment** is a re-creation of an event or occurrence in a way that enables a scientist to support or disprove a hypothesis. In every experiment, the scientist tries to identify if there is a relationship between two events. This can be difficult, because a particular event may involve many separate factors, called **variables.** For example when a bird sings many activities of its nervous and muscular systems are involved. It is also stimulated by a wide variety of environmental factors. Understanding the variables involved in bird song production might seem an impossible task. To help unclutter such a situation, scientists break it up into a series of simple questions and use a *controlled experiment* to answer each question.

A **controlled experiment** allows scientists to construct a situation so that only one variable is present. A typical controlled experiment includes two groups: one group in which the variable is manipulated in a particular way and one group in which there is no manipulation. The group in which there is no manipulation of the variable is called the **control group;** the other group is called the **experimental group.**

The situation involving bird song production would have to be broken down into a large number of simple questions, such as the following:

Do both males and females sing?
Do they sing during all parts of the year?
Is the song the same in all cases?
Do some birds sing more than others?
What parts of their body are used to produce the song?
What situations cause birds to start or stop singing?

Each question would provide the basis for the construction of a hypothesis, which could be tested by an experiment. Each experiment would provide information about a small part of the total process of bird song production. For example, in order to test the hypothesis that male sex hormones produced by the testes are involved in stimulating male birds to sing, an experiment could be performed in which one group of male birds had their testes removed (the experimental group) but the control group was allowed to develop normally.

The presence or absence of testes would be manipulated by the scientist in the experiment and would be the **independent variable.** The singing behavior of the males would be the **dependent variable,** because, if sex hormones are important, the singing behavior observed will change, depending on whether the males have testes or not (the independent variable). In an experiment, there should be only one independent variable, and the dependent variable is expected to change as a direct result of the manipulation of the independent variable. After the experiment, the new data (facts) gathered would be analyzed. If there were no differences in singing between the two groups, scientists could conclude that the independent variable (presence or absence of testes) evidently did not have a cause-and-effect relationship with the dependent variable (singing). However, if there were a difference, it would be likely that the independent variable caused the difference between the control and experimental groups. In the case of songbirds, removal of the testes does change their singing behavior.

Scientists draw their most *reliable* (trustworthy) conclusions from multiple experiments. This is because random events having nothing to do with the experiment may have altered one set of results and suggest a cause-and-effect relationship when none actually exists. For example, if the experimental group of birds became ill with bird flu, they would not sing. Scientists use several strategies to avoid the effects of random events in their experiments; including using large numbers of animals in experiments and having other scientists repeat their experiments at other locations. With these strategies, it is less likely that random events will lead to false conclusions.

Scientists must try to make sure that an additional variable is not accidentally introduced into experiments. For example, the operation necessary to remove the testes of male birds might cause illness or discomfort in some birds, resulting in less singing. A way to overcome this difficulty would be to subject all the birds to the same surgery but to remove the testes of only half of them. (The control birds would still have their testes.) The results of an experiment are only scientifically convincing when there is just one variable, when the experiment has been repeated many times, and when the results for all experiments are the same.

During experimentation, scientists learn new information and formulate new questions, which can lead to even more experiments. One good experiment can result in many new questions and experiments. For example, the discovery of the structure of the DNA molecule by James D. Watson and Francis W. Crick (1953), resulted in thousands of experiments and stimulated the development of the entire field of molecular biology (figure 1.5).

As the processes of questioning and experimentation continue, it often happens that new evidence continually and consistently supports the original hypothesis and other closely related hypotheses. When the scientific community sees how these hypotheses and facts fit together into a broad pattern, they come together to write a scientific theory or law.

The Development of Theories and Laws

As observations are made and hypotheses are tested, a pattern may emerge that leads to a general conclusion. This process of developing general principles from the examination of many sets of specific facts is called **inductive reasoning,** or **induction.** For example, when people examine hundreds of species of birds, they observe that all kinds lay eggs. From these observations, they may develop the principle that laying eggs is a fundamental characteristic of birds, without examining every species of bird.

FIGURE 1.5 One Discovery Leads to Others
The discovery of the structure of the DNA molecule was followed by much research into how the molecule codes information, how it makes copies of itself, and how the information is put into action.

Once such a principle is established, it can be used to predict additional observations in nature. The process of using general principles to predict the specific facts of a situation is called **deductive reasoning**, or **deduction.** For example, after the general principle that birds lay eggs is established, one might deduce that a newly discovered species of bird also lays eggs. In the process of science, both induction and deduction are important thinking processes used to increase our understanding of the nature of our world and to formulate scientific theories and laws.

You have probably heard people say "I have a theory" about such-and-such an event. However, scientists would say you have a *guess* or a *suspicion* about what is going on, not a theory. When scientists use the term *theory*, they mean something very different. A scientific **theory** is a widely accepted, plausible, general statement about fundamental concepts in science that explain *why* things happen. An example of a biological theory is the germ theory of disease. This theory states that certain diseases, called *infectious* diseases, are caused by living microorganisms that are capable of being transmitted from one person to another. When these microorganisms reproduce within a person and the populations of microorganisms increase, they cause disease. As you can see, this is a very broad statement, which is the result of years of observation, questioning, experimentation, and data analysis. The germ theory of disease provides a broad overview of the nature of infectious diseases and methods for their control. However, we also recognize that each kind of microorganism has particular characteristics, which determine the kind of disease condition it causes and the appropriate methods of treatment. Furthermore, we recognize that there are many diseases that are not caused by microorganisms, such as genetic diseases.

Theories are different from hypotheses. A hypothesis provides a possible explanation for a specific question; a theory is a broad concept that shapes how scientists look at the world and how they frame their hypotheses. For example, when a new disease is encountered, one of the first questions asked is "What causes this disease?" A hypothesis might be constructed, which states, "The disease is caused by a microorganism." This is a logical hypothesis, because it is consistent with the general theory that many kinds of diseases are caused by microorganisms (the germ theory of disease).

Because theories are broad, unifying statements, there are few of them. However, just because theories exist does not mean that testing stops. As scientists continue to gain new information, they may find exceptions to a theory or, rarely, disprove a theory.

A **scientific law** is a uniform or constant fact of nature that describes *what* happens in nature. An example of a biological law is the biogenetic law, which states that all living things come from preexisting living things. Although laws describe what happens and theories describe why things happen, there is one way in which laws and theories are similar. Both laws and theories have been examined repeatedly and are regarded as excellent predictors of how nature behaves.

Communication

One central characteristic of the scientific method is the importance of communication among colleagues. For the most part, science is conducted out in the open, under the critical eyes of others who are interested in the same kinds of questions. An important part of the communication process involves the publication of articles in scientific journals about one's research, thoughts, and opinions. This communication can occur at any point during the process of scientific discovery.

FIGURE 1.6 Communication
One important way that scientists communicate is through publications in scientific journals.

Scientists may ask questions about unusual observations. They may publish preliminary results of incomplete experiments. They may publish reports that summarize large bodies of material. And they may publish strongly held opinions that are not supportable with current data. This provides other scientists with an opportunity to criticize, make suggestions, or agree (figure 1.6). Scientists attend conferences, where they can engage in dialog with colleagues. They also interact in informal ways by phone and the Internet. The result is that most of science is subjected to examination by many minds as it is discovered, discussed, and refined.

Table 1.1 summarizes the processes involved in the scientific method and gives an example of how scientific investigation proceeds from an initial question to the development of theories and laws.

1.2 CONCEPT REVIEW

3. What is the difference between simple correlation and a cause-and-effect relationship?
4. How does a hypothesis differ from a scientific theory or a scientific law?
5. List three objects or processes you use daily that are the result of scientific investigation.
6. The scientific method cannot be used to deny or prove the existence of God. Why?
7. What are controlled experiments? Why are they necessary to support a hypothesis?
8. List the parts of the scientific method.

1.3 Science, Nonscience, and Pseudoscience

Fundamental Attitudes in Science

As you can see from our discussion of the scientific method, a scientific approach to the world requires a certain way of thinking. A scientist is a healthy skeptic who separates facts from opinions (views based solely on personal judgment). Ideas are accepted because there is much supporting evidence from numerous studies, not because influential or famous people have strongly held opinions.

Careful attention to detail is also important. Because scientists publish their findings and their colleagues examine their work, they have a strong desire to produce careful work that can be easily defended. This does not mean that scientists do not speculate and state opinions. When they do, however, they take great care to clearly distinguish scientific facts from personal opinion.

There is also a strong ethic of honesty. Scientists are not saints, but the fact that science is conducted openly in front of one's peers tends to reduce the incidence of dishonesty. In addition, the scientific community strongly condemns and

TABLE 1.1 The Nature of the Scientific Method

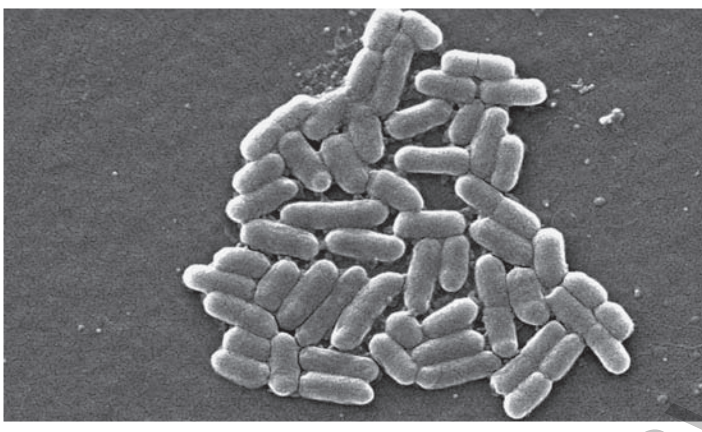
Component of Science Process	Description of Process	Example of the Process in Action
Make observations.	Recognize that something has happened and that it occurs repeatedly. (*Empirical evidence is gained from experience or observation.*)	Doctors observe that many of their patients who are suffering from tuberculosis fail to be cured by the use of the medicines (antibiotics) traditionally used to treat the disease.
Ask questions.	Ask questions about the observation, evaluate the questions, and keep the ones that will be answerable.	Have the drug companies modified the antibiotics? Are the patients failing to take the antibiotics as prescribed? Has the bacterium that causes tuberculosis changed?
Explore other sources of information.	Go to the library. Talk to others who are interested in the same problem. Communicate with other researchers to help determine if your question is a good one or if others have already answered it.	Read medical journals. Contact the Centers for Disease Control and Prevention. Consult experts in tuberculosis. Attend medical conventions. Contact drug companies and ask if their antibiotic formulation has been changed.
Form a hypothesis.	Pose a possible answer to your question. Be sure that it is testable and that it accounts for all the known information. Recognize that your hypothesis may be wrong.	Hypothesis: Tuberculosis patients who fail to be cured by standard antibiotics have tuberculosis caused by antibiotic-resistant populations of the bacterium *Mycobacterium tuberculosis*.
Test the hypothesis (experimentation).	Set up an experiment that will allow you to test your hypothesis using a control group and an experimental group. Be sure to collect and analyze the data carefully.	Set up an experiment in which samples of tuberculosis bacteria are collected from two groups of patients: those who are responding to antibiotic therapy and those who are not responding to antibiotic therapy. Grow the bacteria in the lab and subject them to the antibiotics normally used to see if the bacteria from these two groups of patients respond differently. Experiments consistently show that the patients who are not recovering have strains of bacteria that are resistant to the antibiotic being used.
Find agreement with existing scientific laws and theories or construct new laws or theories.	If your findings are seen to fit with current information, the scientific community will recognize them as being consistent with current scientific laws and theories. In rare instances, a new theory or law may develop as a result of research.	Your results are consistent with the following laws and theories: • Mendel's laws of heredity state that characteristics are passed from parent to offspring. • The theory of natural selection predicts that, when populations of *Mycobacterium tuberculosis* are subjected to antibiotics, the bacteria that survive will pass on their ability to survive exposure to antibiotics to the next generation and that the next generation will have a higher incidence of these characteristics.
Form a conclusion and communicate it.	You arrive at a conclusion. Throughout the process, communicate with other scientists by both informal conversation and formal publications.	You conclude that the antibiotics are ineffective because the bacteria are resistant to the antibiotics. You write a scientific article describing the experiment and your conclusions.

severely penalizes those who steal the ideas of others, perform shoddy science, or falsify data. Any of these infractions can lead to the loss of one's job and reputation.

Theoretical and Applied Science

The scientific method has helped us understand and control many aspects of our natural world. Some information is extremely important in understanding the structure and functioning of things in nature but at first glance appears to have little practical value. For example, the discovery of the structure of deoxyribonucleic acid (DNA) answered a fundamental question about the nature of genetic material. Many people asked why such research would be done or funded by their taxes. However, as individuals began to use this new knowledge, they developed many practical applications for it. For example, scientists known as *genetic engineers* have altered the chemical code system of microorganisms, in order to produce many new drugs, such as antibiotics, hormones, and enzymes. To do this, genetic engineers needed information from the basic, theoretical sciences of microbiology, molecular biology, and genetics (figure 1.7).

Another example of how fundamental research can lead to practical application is the work of Louis Pasteur (1822–1895), a French chemist and microbiologist. Pasteur was interested in the highly theoretical question, "Could life be generated from nonliving material?" Much of his theoretical work led to practical applications in disease control. His theory that microorganisms cause diseases and decay led to the development of vaccinations against rabies and the development of pasteurization for the preservation of foods (figure 1.8).



(a)

(b)

FIGURE 1.7 Genetic Engineering
Genetic engineers have modified the genetic code of bacteria, such as *Escherichia coli*, commonly found in the colon *(a)* to produce useful products, such as vitamins, protein, and antibiotics. The bacteria can be cultured in vats, where the genetically modified bacteria manufacture their products *(b)*. The products can be extracted from the mixture in the vat.

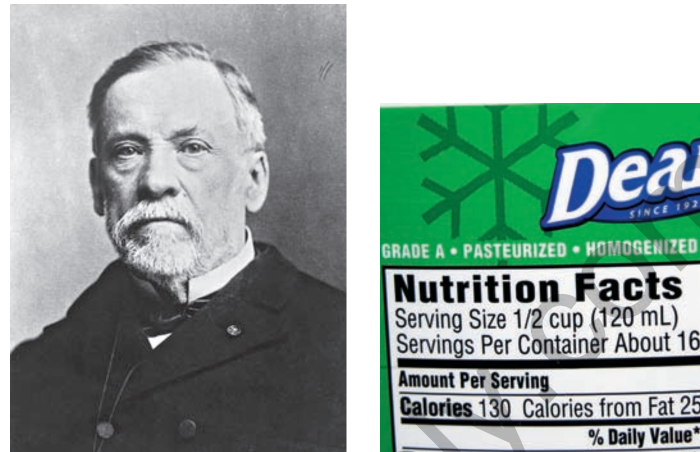


FIGURE 1.8 Louis Pasteur and Pasteurized Milk
Louis Pasteur (1822–1895) performed many experiments while he studied the question of the origin of life, one of which led directly to the food-preservation method now known as pasteurization.

Science and Nonscience

Both scientists and nonscientists seek to gain information and improve understanding in their fields of study. The differences between science and nonscience are based on the assumptions and methods used to gather and organize information and, most important, the way the assumptions are tested. The difference between a scientist and a nonscientist is that a scientist continually challenges and tests principles and assumptions to determine cause-and-effect relationships. A nonscientist may not be able to do so or may not believe that this is important. For example, a historian may have the opinion that, if President Lincoln had not appointed Ulysses S. Grant to be a general in the Union Army, the Confederate States of America would have won the Civil War. Although there can be considerable argument about the topic, there is no way that it can be tested. Therefore, such speculation about historical events is not scientific. This does not mean that history is not a respectable field of study, only that it is not science. Historians simply use the standards of critical thinking that are appropriate to their field of study and that can provide insights into the role military leadership plays in the outcome of conflicts.

Once you understand the scientific method, you won't have any trouble identifying astronomy, chemistry, physics, geology, and biology as sciences. But what about economics, sociology, anthropology, history, philosophy, and literature? All of these fields may make use of certain central ideas that are derived in a logical way, but they are also nonscientific in some ways. Some things are beyond science and cannot be approached using the scientific method. Art, literature, theology, and philosophy are rarely thought of as sciences. They are concerned with beauty, human emotion, and speculative thought, rather than with facts and verifiable laws.

Many fields of study have both scientific and nonscientific aspects. For example, the styles of clothing people wear are often shaped by the artistic creativity of designers and shrewd marketing by retailers. Originally, animal hides, wool, cotton, and flax were the only materials available, and the color choices were limited to the natural colors of the material or dyes extracted from nature. Scientific discoveries led to the development of synthetic fabrics and dyes, machines to construct clothing, and new kinds of fasteners that allowed for new styles and colors (figure 1.9).

Similarly, economists use mathematical models and established economic laws to make predictions about future economic conditions. However, the reliability of predictions is a central criterion of science, so the regular occurrence of unpredicted economic changes indicates that economics is far from scientific. Many aspects of anthropology and sociology are scientific, but they cannot be considered true sciences, because many of the generalizations in these fields cannot be tested by repeated experimentation. They also do not show a significantly high degree of cause-and-effect, or they have poor predictive value.

Pseudoscience

Pseudoscience (*pseudo* = false) is a deceptive practice that uses the appearance or language of science to convince, confuse, or mislead people into thinking that something has scientific validity. When pseudoscientific claims are closely examined, they are not found to be supported by unbiased tests.

For example, nutrition is a respectable scientific field; however, many individuals and organizations make unfounded claims about their products and diets (figure 1.10). Because of nutritional research, we all know that we must obtain certain nutrients, such as amino acids, vitamins, and minerals, from the food we eat or we may become ill. However, in most cases, it has not been demonstrated that the nutritional supplements so vigorously advertised are as useful or desirable as claimed. Rather, the advertisements select bits of scientific information about the fact that amino acids, vitamins, and minerals are essential to good health and then use this information to create the feeling that nutritional supplements are necessary or can improve health. In reality, the average person eating a varied diet can obtain all these nutrients in adequate amounts.

Another related example involves the labeling of products as organic or natural. Marketers imply that organic or natural

(a) **(b)**

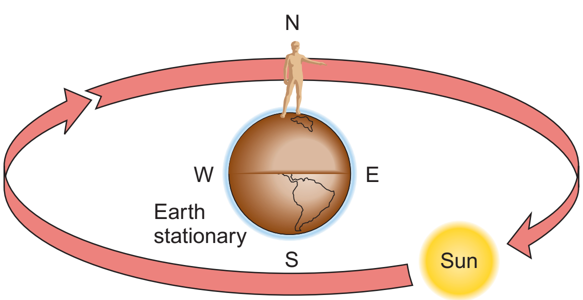
FIGURE 1.9 Science and Culture
Although the design of clothing is not a scientific enterprise, scientific discoveries have altered the choices available. *(a)* Originally, clothing could be made only from natural materials with simple construction methods. *(b)* The discovery of synthetic fabrics and dyes and the invention of specialized fasteners resulted in increased variety and specialization of clothing.

FIGURE 1.10 Pseudoscience—"Nine out of 10 Doctors Surveyed Recommend Brand X"
Pseudoscience is designed to mislead. There are several ways in which this image and the statement can be misleading. You can ask yourself two questions. First, is the person in the white coat a physician? Second, how many doctors were asked for a recommendation and how were they selected? If only 10 doctors were asked, the sample size was too small. Perhaps the doctors who participated were selected to obtain the desired outcome. Finally, the doctors could have been surveyed in such a way as to obtain the desired answer, such as "Would you recommend Brand X over Dr. Pete's snake oil?"

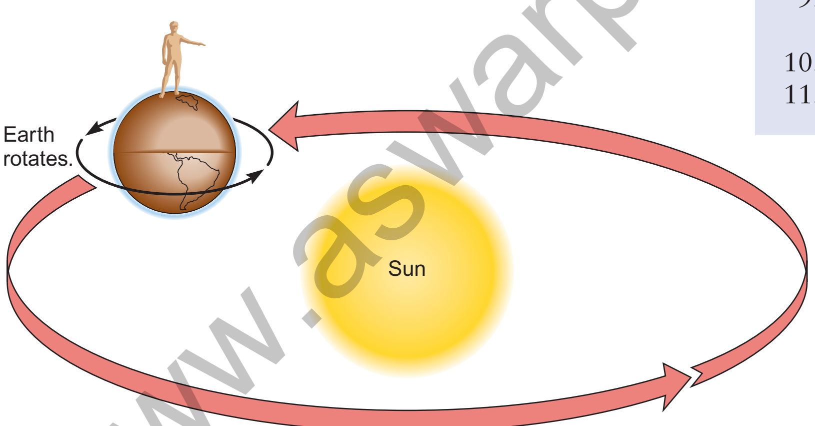
products have greater nutritive value because they are organically grown (grown without pesticides or synthetic fertilizers) or because they come from nature. Although there are questions about the health effects of trace amounts of pesticides in foods, no scientific study has shown that a diet of natural or organic products has any benefit over other diets. The poisons curare, strychnine, and nicotine are all organic molecules that are produced in nature by plants that can be grown organically, but we wouldn't want to include them in our diet.

The Limitations of Science

Science is a way of thinking that involves testing possible answers to questions. Therefore, the scientific method can be applied only to questions that have factual bases. Ethical, moral, and religious concerns are not scientific endeavors. Questions about such topics cannot be answered using the scientific method. What makes a painting great? What is the best type of music? Which wine is best? Is there a God? These questions are related to values, beliefs, and tastes; therefore, the scientific method cannot be used to answer them.



(a) Scientists thought that the Sun revolved around the Earth.



(b) We now know that the Earth rotates on its axis and revolves around the Sun.

FIGURE 1.11 Science Is Willing to Challenge Previous Beliefs
Science must always be aware that new discoveries may force a reinterpretation of previously held beliefs. *(a)* Early scientists thought that the Sun revolved around the Earth. This was certainly a reasonable theory at the time. People saw the Sun rise in the east and set in the west, and it looked as if the Sun moved through the sky. *(b)* Today, we know that the Earth revolves around the Sun and that the apparent motion of the Sun in the sky is caused by the Earth rotating on its axis.

Science is also limited by the ability of people to figure out how the natural world works. People are fallible and do not always come to the right conclusions because they lack information or misinterpret it. However science is self-correcting and, as new information is gathered, old, incorrect ways of thinking are changed or discarded. For example, at one time scientists were sure that the Sun went around the Earth. They observed that the Sun rose in the east and traveled across the sky to set in the west. Because scientists could not feel the Earth moving, it seemed perfectly logical that the Sun traveled around the Earth. Once they understood that the Earth rotated on its axis, they began to realize that the rising and setting of the Sun could be explained in other ways. A completely new concept of the relationship between the Sun and the Earth developed (figure 1.11). Although this kind of study seems rather primitive to us today, this change in thinking about the relationship between the Sun and the Earth was a very important step forward in our understanding of the universe.

People need to understand that science cannot answer all the problems of our time. Although science is a powerful tool, there are many questions it cannot answer and many problems it cannot solve. Most of the problems societies face are generated by the behavior and desires of people. Famine, drug abuse, war, and pollution are human-caused and must be resolved by humans. Science provides some important tools for social planners, politicians, and ethical thinkers. However, science does not have, nor does it attempt to provide, all the answers to the problems of the human race. Science is merely one of the tools at our disposal.

1.3 CONCEPT REVIEW

9. What is the difference between science and nonscience?
10. How can you identify pseudoscience?
11. Why is political science not a science?

1.4 The Science of Biology

The science of biology is, broadly speaking, the study of living things. However, there are many specialty areas of biology, depending on the kind of organism studied or the goals a person has. Some biological studies are theoretical, such as establishing an evolutionary tree of life, understanding the significance of certain animal behaviors, or determining the biochemical steps involved in photosynthesis. Other fields of biology are practical—for example, medicine, crop science, plant breeding, and wildlife management. There is also just plain fun biology—fly-fishing for trout or scuba diving on a coral reef.

At the beginning of the chapter, we defined *biology* as the science that deals with life. But what distinguishes living things from those that are not alive? You would think that a biology textbook could answer this question easily. However, this is more than just a theoretical question. In recent years, it has become necessary to construct legal definitions of *life*, especially of when it begins and ends. The legal definition of *death* is important, too, because it may determine whether a person will receive life insurance benefits or if body parts may be used in transplants. In the case of a heart transplant, the person donating the heart may be legally "dead" but the heart certainly isn't. It is removed while it is still alive, even though the person is not. In other words, there are different kinds of death. There is death of the whole living unit and death of each cell within the living unit. A person actually "dies" before every cell has died. Death, then, is the absence of life, but that still doesn't tell us what life is.

Similarly, there has been much controversy over the question of when life begins. Certainly, the egg and the sperm that participate in fertilization are both alive, as is the embryo that results. However, from a legal and moral perspective, the question of when an embryo is considered a separate living thing is a very different proposition.

What Makes Something Alive?

Living things have abilities and structures not found in things that were never living. The ability to interact with their surroundings to manipulate energy and matter is unique to living things. **Energy** is the ability to do work or cause things to move. **Matter** is anything that has mass and takes up space. Developing an understanding of how living things modify matter and use energy will help you appreciate how living things differ from nonliving objects. Living things show five characteristics that nonliving things do not: (1) unique structural organization, (2) metabolic processes, (3) generative processes, (4) responsive processes, and (5) control processes. It is important to recognize that, although these characteristics are typical of all living things, they may not all be present in each organism at every point in time. For example, some individuals may reproduce or grow only at certain times. This section briefly introduces these basic characteristics of living things, which will be expanded on in the rest of the text.

Unique Structural Organization

The **unique structural organization** of living things can be seen at the molecular, cellular, and organism levels. Molecules such as DNA and proteins are produced by living things and are unique to each kind of living thing. **Cells** are the fundamental structural units of all living things. Cells have an outer limiting membrane and several kinds of internal structures. Each structure has specific functions. Some living things, such as people, consist of trillions of cells, whereas others, such as bacteria and yeasts, consist of only one cell. Nonliving materials, such as rocks, water, and gases, do not have a cellular structure.

An **organism** is any living thing that is capable of functioning independently, whether it consists of a single cell or a complex group of interacting cells (figure 1.12). Each kind of organism has specific structural characteristics, which it

FIGURE 1.12 Structural Organization
Each organism, whether it is simple or complex, independently carries on metabolic, generative, responsive, and control processes. It also contains special molecules, a cellular structure, and other structural components. DNA is a molecule unique to living things. Some organisms, such as yeast or the protozoan *Euplotes*, consist of single cells, whereas others, such as orchids and humans, consist of many cells organized into complex structures.

shares with all other organisms of the same kind. You recognize an African elephant, a redwood tree, or a sunflower as having certain characteristics, although other organisms may not be as easy to distinguish.

Metabolic Processes

All the chemical reactions involving molecules required for a cell to grow, reproduce and make repairs are referred to as its **metabolism**. Metabolic properties keep a cell alive. The energy that organisms use is stored in the chemical bonds of complex molecules. Even though different kinds of organisms have different ways of metabolizing **nutrients** or food, we are usually talking about three main activities: taking in nutrients, processing them, and eliminating wastes.

Energy is expended when living things take in nutrients (raw materials) from their environment (figure 1.13). Many animals take in these materials by eating other organisms.

FIGURE 1.13 Metabolism
The metabolic processes of this hummingbird include the intake of nutrients in the form of nectar from flowers.

Microorganisms and plants absorb raw materials into their cells to maintain their lives. Nutrient processing takes place once the nutrients are inside the organism or its cells. Most animals have organs that assist in processing nutrients. In all organisms, once inside cells, nutrients enter a network of chemical reactions. These reactions process the nutrients to manufacture new parts, make repairs, reproduce, and provide energy for essential activities. Waste elimination occurs because not all materials entering a living thing are valuable to it. Some portions of nutrients are useless or even harmful, and organisms eliminate these portions as waste. Metabolic processes also produce unusable heat energy, which can be considered a waste product. Microorganisms, plants, and many tiny animals eliminate useless or harmful materials through their cell surfaces, but more complex animals have special structures for getting rid of these materials.

Generative Processes

Generative processes are activities that result in an increase in the size of an organism—*growth*—or an increase in the number of individuals in a population—*reproduction* (figure 1.14). Growth and reproduction are directly related to metabolism, because neither can occur without gaining and processing nutrients.

During growth, living things add to their structure, repair parts, and store nutrients for later use. In large organisms, growth usually involves an increase in the number of cells present.

Reproduction is also an essential characteristic of living things. Because all organisms eventually die, life would cease to exist without reproduction. Organisms can reproduce in two basic ways. Some reproduce by *sexual reproduction*, in which two individuals each contribute sex cells, which leads to the creation of a new, unique organism. *Asexual reproduction* (without sex) occurs when an organism makes identical

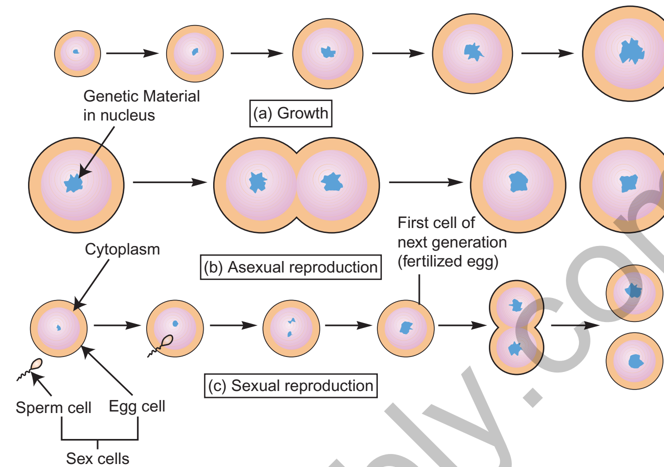


FIGURE 1.14 Generative Processes
Generative processes as they relate to cells.

copies of itself. Many kinds of plants and animals reproduce asexually when a part of the organism breaks off the parent organism and regenerates the missing parts.

Responsive Processes

Responsive processes allow organisms to react to changes in their surroundings in a meaningful way. There are three categories of responsive processes: *irritability, individual adaptation*, and *evolution*, which is also known as *adaptation of populations*.

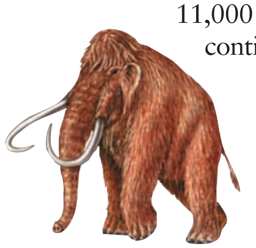
Irritability is an individual's ability to recognize that something in its surroundings has changed (a stimulus) and respond rapidly to it, such as your response to a loud noise, beautiful sunset, or bad smell. The response occurs only in the individual receiving the stimulus, and the reaction is rapid, because there are structures and processes already in place that receive the stimulus and cause the response. One-celled organisms, such as protozoa and bacteria, can sense and orient to light. Many plants orient their leaves to follow the sun. Animals use sense organs, nerves, and muscles to monitor and respond to changes in their environment.

Individual adaptation also results from an organism's reaction to a stimulus, but it is slower than an irritability response, because it requires growth or some other fundamental change in an organism. For example, during the summer the varying hare has brown fur. However, the shortening days of autumn cause the genes responsible for the production of brown pigment to be "turned off" and new, white hair grows (figure 1.15). Plants also show individual adaptation to changing day length. Lengthening days stimulate the production of flowers and shortening days result in falling leaves. Similarly, your body will adapt to lower oxygen levels by producing more oxygen-carrying red blood cells. Many athletes like to train at high elevations because the increased number of red blood cells resulting from exposure to low oxygen levels delivers more oxygen to their muscles.

Evolution involves genetic changes in the characteristics displayed within a population. It is a slow change in the genetic makeup of a *population* of organisms over many generations.

FIGURE 1.15 Individual Adaptation
The change in coat color of this varying hare is a response to changing environmental conditions.

Evolution enables a species (a population of a specific kind of organism) to adapt to long-term changes in its environment (figure 1.16). For example, between about 1.8 million and 11,000 years ago, the climate was cold and large continental glaciers covered northern Europe and North America. The plants and animals were adapted to these conditions. As the climate slowly warmed over the last 11,000 years, many of these species went extinct, whereas others adapted and continue in a modified form. For example, mammoths and mastodons were unable to adapt to the changing environment and became extinct, but some species, such as moose, elk, and



wolves, were able to adapt to a warming environment and still exist today. Similarly, the development of the human brain and its ability to reason allowed our prehuman ancestors to craft and use tools. Their use of tools allowed them to survive and succeed in a great variety of environmental conditions.

Control Processes

Control processes are mechanisms that ensure an organism will carry out all metabolic activities in the proper sequence (*coordination*) and at the proper rate (*regulation*).

Coordination occurs within an organism at several levels. At the metabolic level, all the chemical reactions of an organism are coordinated and linked together in specific pathways. The control of all the reactions ensures efficient, stepwise handling of the nutrients needed to maintain life. The molecules responsible for coordinating these metabolic reactions are known as *enzymes*. **Enzymes** are molecules, produced by organisms, that are able to control the rate at which life's chemical reactions occur. Enzymes also regulate the amount of nutrients processed into other forms. Enzymes will be discussed in detail in chapter 5.

Coordination also occurs at the organism level. When an insect walks, the muscles of its six legs are coordinated, so that orderly movement results. In plants, regulatory chemicals assure the proper sequence of events that result in growth in the spring and early summer, followed by flowering and the development of fruit later in the year.

Regulation involves altering the rate of processes. Many of the internal activities of an organism are interrelated and regulated, so that a constant internal environment is maintained. The process of maintaining a constant internal environment is called **homeostasis.** For example, when we begin to exercise we use up oxygen more rapidly, so the amount of oxygen in the blood falls. In order to maintain a constant internal environment, the body must obtain more oxygen. This requires more rapid contractions of the muscles that cause breathing and a more rapid and

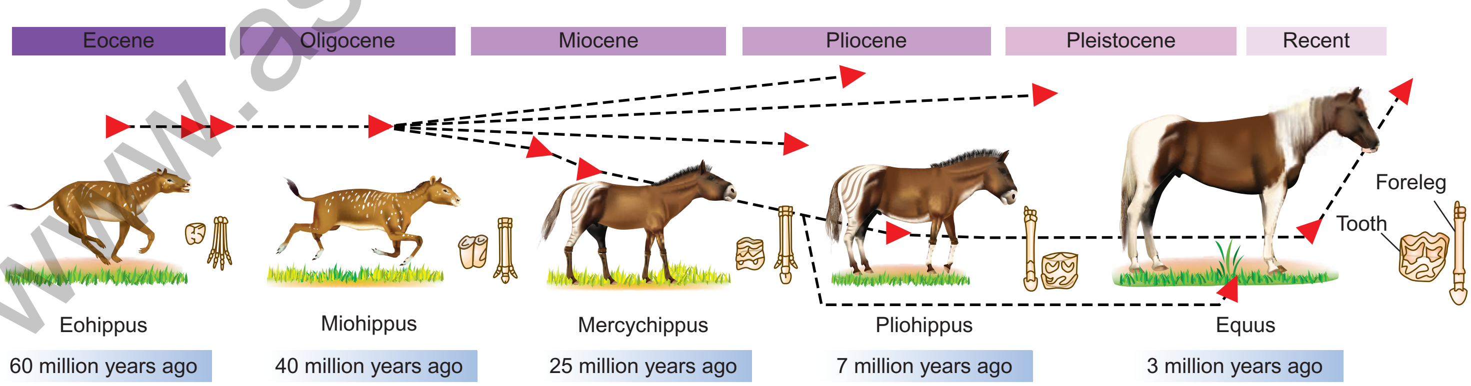


FIGURE 1.16 Evolution
A principle that all scientists work with is the fact that things change over time. We know that chemicals react to become other kinds of substances, mountains crumble, rivers change course, and organisms reproduce and die. Evolution is also a change, but one that takes generations of time and results in descendents with a different genetic makeup than their ancestors. This sequence shows five species that illustrate that body size, leg structure, and food habits changed over time in horses.

forceful pumping of the heart to get blood to the lungs. These activities must occur together at the right time and at the correct rate; when they do, the level of oxygen in the blood will remain normal while supporting the additional muscular activity (figure 1.17).

The Levels of Biological Organization and Emerging Properties

At this point you might be asking, "How can I possibly keep all this in my head?" Even biologists have difficulty keeping track of the vast amount of information being generated by researchers around the world. When you or biologists seek solutions to problems, it should be viewed at several levels at the same time. Doing this helps scientists create connections between different concepts. To be able to do this yourself, you must understand what these levels are. In order to help you, and biologists, conceptualize the relationships that exist at these various levels, this information has been organized into table 1.2. Return to this table as you move through the text to jog your memory and regain your perspective should you get confused.

Scientists recognize these levels as a ladder of increasing complexity from atoms to biosphere, each displaying new properties not seen on the previous step. These never-before-seen features that result from

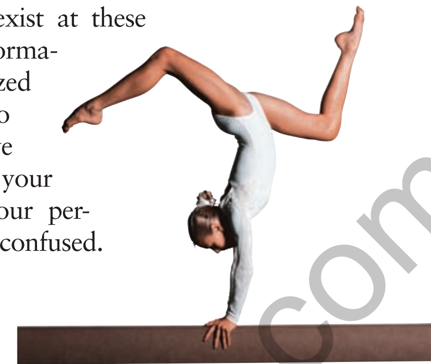


FIGURE 1.17 Control Process Working the balance beam involves coordination of heart rate, breathing rate, and muscular activity in a controlled manner.

TABLE 1.2 Levels of Organization for Living Things

Level	Characteristics/Explanation	Example/Application
Biosphere	The worldwide ecosystem	Human activity affects the climate of the Earth. Global climate change and the hole in ozone layer are examples of human impacts on the biosphere.
Ecosystem	Communities (groups of populations) that interact with the physical world in a particular place	The Everglades ecosystem involves many kinds of organisms, the climate, and the flow of water to south Florida.
Community	Populations of different kinds of organisms that interact with one another in a particular place	The populations of trees, insects, birds, mammals, fungi, bacteria, and many other organisms interact in any location.
Population	A group of individual organisms of a particular kind	The human population currently consists of over 6 billion individuals. The current population of the California condor is about 220 individuals.
Organism	An independent living unit	Some organisms consist of many cells—you, a morel mushroom, a rose bush. Others are single cells—yeast, pneumonia bacterium, *Amoeba*.
Organ system	A group of organs that work together to perform a particular function	The circulatory system consists of a heart, arteries, veins, and capillaries, all of which are involved in moving blood from place to place.
Organ	A group of tissues that work together to perform a particular function	An eye contains nervous tissue, connective tissue, blood vessels, and pigmented tissues, all of which are involved in sight.
Tissue	Groups of cells that work together to perform particular functions	Blood, muscle cells, and the layers of the skin are all groups of cells and each performs a specific function.
Cell	The smallest unit that displays the characteristics of life	Some organisms are single cells. Within multicellular organisms are several kinds of cells—heart muscle cells, nerve cells, white blood cells.
Molecules	Specific arrangements of atoms	Living things consist of special kinds of molecules, such as proteins, carbohydrates, and DNA, as well as common molecules, such as water.
Atoms	The fundamental units of matter	There are about 100 different kinds of atoms such as hydrogen, oxygen, and nitrogen.

FIGURE 1.18 Emerging Properties
The properties you recognize as a car only become evident when the component parts are correctly assembled.

the interaction of simple components when they form much more complex substances are called **emergent properties** (figure 1.18). For example, when atoms on the first level interact to form molecules on the second level, new properties emerge that are displayed by the molecules (e.g., the ability to serve as genetic material). In turn, these molecules work together to form the parts of the next higher level, cells. Again, cells have a whole new set of emergent properties—all of life's characteristics. Continuing on, cells become organized into tissues; tissues into organs; organs into organ systems; and organ systems into organisms. All of these levels of organization exist within you as an individual.

These levels continue to provide you with a biological context for the world around you. Organisms are grouped into populations on the basis of where they live. Several populations are defined as a community. Now, the levels of organization start to include nonliving environmental characteristics, too. Communities and their environment form ecosystems. Several ecosystems form biomes and, finally, several biomes form the biosphere of our planet. As before, novel properties emerge as you rise through the chart. At the highest level, some scientists begin to view our planet as a type of living entity that has unique emergent properties not found at lower levels of organization.

The Significance of Biology in Our Lives

To a great extent, we owe our high standard of living to biological advances in two areas: food production and disease control. Plant and animal breeders have modified organisms to yield greater amounts of food than did older varieties. A good example is the changes that have occurred in corn. Corn, a kind of grass, produces its seeds on a cob. The original corn plant had very small cobs, which were perhaps only 3 or 4 centimeters long. Selective breeding has produced varieties of corn with much larger cobs and more seeds per cob, increasing the yield greatly. In addition, plant breeders have created varieties, such as sweet corn and popcorn, with special characteristics. Similar improvements have occurred in wheat, rice, oats, other cereal grains and fruits (figure 1.19). The improvements in the plants, along with better farming practices (also brought about through biological experimentation), have greatly increased food production.

Animal breeders also have had great successes. The pig, chicken, and cow of today are much different animals from those available even 100 years ago. Chickens lay more eggs, beef cattle grow faster, and dairy cows give more milk. All these improvements increase the amount of food available and raise our standard of living.

Biological research has also improved food production by developing controls for the disease organisms, pests, and weeds that reduce yields. Biologists must understand the nature of these harmful organisms to develop effective control methods.

There also has been fantastic progress in the area of human health. An understanding that diseases such as cholera, typhoid fever, and dysentery spread from one person to another through the water supply led to the development of treatment plants for sewage and drinking water. Recognizing that diseases such as botulism and salmonella spread through food led to guidelines for food preservation and preparation that greatly reduced the incidence of these diseases. Many other diseases, such as polio, whooping cough, measles, and mumps, can be prevented by vaccinations (How Science Works 1.1). Unfortunately, the vaccines have worked so well that some people no longer bother to get them. Furthermore, we have discovered that adults need to be revaccinated for some of these diseases. Therefore, we see that some diseases, such as diphtheria, whooping cough, and chicken pox are reappearing among both children and adults.


(a)

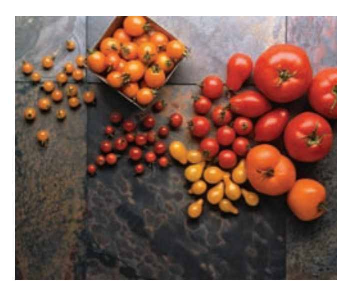

(b)

FIGURE 1.19 Biological Research Improves Food Production
(a) One food that has seen a vast increase in production and variation is the tomato. Tomatoes (*Lycopersicon* sp.) originated on the western coast of South America in Peru. Wild tomato species have tiny fruits, and only the red ones are edible. *(b)* Over the centuries, selective breeding and biotechnology have resulted in the generation of hundreds of varieties of this vegetable.

HOW SCIENCE WORKS 1.1

Edward Jenner and the Control of Smallpox

Edward Jenner (1749–1823) was born in Berkeley, Gloucestershire, in western England. He wanted to become a doctor, so he became an apprentice to a local doctor. This was the typical training for physicians at that time. After his apprenticeship, he went to London and studied with an eminent surgeon. In 1773, he returned to Berkeley and practiced medicine there for the rest of his life.

At that time in Europe and Asia, smallpox was a common disease, which nearly everyone developed, usually early in life. Many children died of it, and many who survived were disfigured by scars. It was known that people who had had smallpox once were protected from future infection. If children were deliberately exposed to smallpox when they were otherwise healthy, a mild form of the disease often developed, and they were protected from future smallpox infections. Indeed, in the Middle East, people were deliberately infected by scratching material from the pocks of an infected person into their skin. This practice was introduced to England in 1717 by Lady Mary Wortley Montagu, the wife of the ambassador to Turkey. She had observed the practice of deliberate infection in Turkey and had had her own children inoculated. This practice had become common in England by the early 1700s, and Jenner carried out such deliberate inoculations as part of his practice. He also frequently came into contact with individuals who had smallpox, as well as people infected with cowpox—a mild disease similar to smallpox.

In 1796, Jenner introduced a safer way to protect against smallpox as a result of his 26-year study of cowpox and smallpox. Jenner had made two important *observations*. First, many milkmaids and other farmworkers developed a mild illness, with pocklike sores, after milking cows that had cowpox sores on their teats. Second, very few of those who had been infected with cowpox became sick with smallpox. He asked the *question* "Why don't people who have had cowpox get smallpox?" He developed the *hypothesis* that the mild disease caused by cowpox somehow protected them from the often fatal smallpox. This led him to perform an *experiment*. In his first experiment, he took puslike material from a sore on the hand of a milkmaid named Sarah Nelmes and rubbed it into small cuts on the arm of an 8-year-old boy named James Phipps. James developed the normal mild infection typical of cowpox and completely recovered. Subsequently, Jenner inoculated James with material from a smallpox patient. (Recall that this was a normal practice at the time.) James did not develop any disease. Jenner's *conclusion* was that deliberate exposure to cowpox had protected James from smallpox. Eventually the word *vaccination* was used to describe the process. It was derived from the Latin words for *cow* (*vacca*) and *cowpox disease* (*vaccinae*) (box figure).

When these results became known, public reaction was mixed. Some people thought that vaccination was the work of the devil. However, many European rulers supported Jenner by encouraging their subjects to be vaccinated. Napoleon and the empress of Russia were very influential and, in the United States, Thomas Jefferson had some members of his family vaccinated. Many years later, following the development of the *germ theory of disease*, it was discovered that cowpox and smallpox are caused by viruses that are similar in structure. Exposure to the cowpox virus allows the body to develop immunity against both the cowpox virus and the smallpox virus. In the mid-1900s a slightly different virus was used to develop a vaccine against smallpox, which was used worldwide. In 1979, almost 200 years after Jenner developed his vaccination, the Centers for Disease Control and Prevention (CDC) in the United States and the World Health Organization (WHO) of the United Nations declared that smallpox had been eradicated.

The painting depicts Edward Jenner vaccinating James Phipps.

They have not been eliminated, and people who are not protected by vaccinations are still susceptible to them. By helping us understand how the human body works, biological research has led to the development of treatments that can control chronic diseases, such as diabetes, high blood pressure, and even some kinds of cancer. Unfortunately, all these advances in health contribute to another major biological problem: the increasing size of the human population.

The Consequences of Not Understanding Biological Principles

A lack of understanding biological principles, and the inability to distinguish between valid scientifically obtained facts and personal opinions, can have significant consequences. Some people practice "selective acceptance of scientific evidence." They have "faith" in the health products and procedures that have

HOW SCIENCE WORKS 1.1 (*continued*)

Recommended Immunization Schedule United States, 2007

Vaccine/ Age	Birth	1 month	2 months	4 months	6 months	12 months	15 months	18 months	24 months	4–6 years	11–12 years	13–18 years	19–49 years	50–64 years	65 or older
Hep B (hepatitis B)	First	Second			Third				Hep B series if needed (3 doses)						
DTP: diphtheria, tetanus, pertussis (whooping cough)			First	Second	Third		Fourth			Fifth	Tetanus & diphtheria		1 dose tetanus every 10 years		
HIB (*Haemophilus* influenzae type B - influenza)			First	Second	Third	Fourth									
IPV (inactivated polio vaccine)			First	Second	Third					Fourth					
PCV (Pneumococcal conjugate - pneumonia)			First	Second	Third	Fourth			Additional vaccinations if high-risk				1–2 doses		1 dose
MMR: Measles, mumps, rubella (German measles)						First				Second			1–2 doses	1 dose	
Varicella (chicken pox)						First				Second			2 doses		
Influenza (flu)					2 doses						If high risk				
MPSV4 (Meningococcal - viral meningitis)											1 or more doses if high-risk				
HPV (Human papilloma virus)											3 doses (female)				
Rotavirus			1 dose												
	Source: Centers for Disease Control and Prevention														

Today, vaccinations (immunizations) are used to control many diseases that used to be common. Many of them were known as childhood diseases, because essentially all children got them. Today, they are rare in populations that are vaccinated. The following chart shows the schedule of immunizations recommended by the Advisory Committee on Immunization Practices of the American Academy of Pediatrics and American Academy of Family Physicians.

resulted from "good science" (e.g., antibiotics, heart transplants) but don't "believe" or have "faith" in others (e.g., vaccinations, genetic engineering, stem cells).

Inability to See a Bigger Picture

There are some people who believe that you can get the flu by getting the vaccine in spite of scientific evidence to the contrary. While the vaccine may cause certain side effects (problems that occur in addition to the desired healing effect), it does not contain any viruses capable of causing infection. These people (1) confuse the side effects with actual flu symptoms; (2) don't realize that the vaccine they received does not protect against other, related strains of influenza virus; or (3) may have already been infected before receiving the vaccine. In fact, by refusing to get vaccinated they jeopardize others in their community. By being vaccinated and becoming immune to the virus, they serve as a barrier to the spread of the virus, helping to prevent others from becoming infected. If enough people become immune as the result of immunization, there is less chance that others will get the illness.

Lack of Understanding the Interconnectedness of Ecological Systems

At one time, it was thought that the protection of specific land areas would preserve endangered ecosystems. However, it is now recognized that many activities outside park and preserve boundaries are also important. For example, although Everglades National Park in Florida has been well managed by the National Park Service, this ecosystem is experiencing significant destruction. Commercial and agricultural development adjacent to the park has caused groundwater levels in the Everglades to drop so low that the park's very existence is threatened. Fertilizer has entered the park from surrounding farmland and has encouraged the growth of plants that change the nature of the ecosystem. In 2000, Congress authorized the expenditure of $1.4 billion to begin to implement a plan that will address the problems of water flow and pollution. The major goals are to reduce the amount of nutrients entering from farms and to increase the flow of water to the Everglades from Lake Okeechobee to the north.

The Damage Caused by Exotic Species

In North America, the introduction of exotic (foreign) species of plants and animals has had disastrous consequences in a number of cases (figure 1.20). Both the American chestnut and the American elm have been nearly eliminated by diseases that were introduced by accident. Another accidental introduction, the zebra mussel, has greatly altered freshwater lakes and rivers in the central and eastern parts of the United States. They filter tiny organisms from the water and deprive native organisms of this food source. In addition, they attach themselves to native mussels, often causing their death.

Other organisms have been introduced on purpose because of shortsightedness or a lack of understanding about biology. The European starling and the English (house) sparrow were both introduced into this country by people who thought they were doing good. Both of these birds have multiplied greatly and have displaced some native birds. Many people want to have exotic animals as pets. When these animals escape or are intentionally released, they can become established in local ecosystems and endanger native organisms. For example, Burmese pythons are commonly kept as pets. Today, they are common in the Everglades and kill and eat native species. Large pythons have even been observed attacking alligators. The introduction of exotic plants has also caused problems. At one time, people were encouraged to plant a shrub known as autumn olive as a wildlife food. The plant produces many small fruits, which are readily eaten by many kinds of birds and mammals. However, because the animals eat the fruits and defecate the seeds everywhere, autumn olive spreads rapidly. Today, it is recognized as an invasive plant needing to be controlled.

Starling

Zebra Mussels

FIGURE 1.20 Exotic Animals
Exotic organisms such as starlings and zebra mussels have altered natural ecosystems by replacing native species.

Ethical Concerns

Advances in technology and our understanding of human biology have presented us with difficult ethical issues, which we have not been able to resolve satisfactorily. Major advances in health care have prolonged the lives of people who would have died if they had lived a generation earlier. Many of the techniques and machines that allow us to preserve and extend life are extremely expensive and are therefore unavailable to most citizens of the world. Many people lack even the most basic health care, while people in the rich nations of the world spend millions of dollars to have cosmetic surgery and to keep comatose patients alive with the assistance of machines.

Future Directions in Biology

Where do we go from here? Although the science of biology has made major advances, many problems remain to be solved. For example, scientists are seeking major advances in the control of the human population, and there is a continued interest in the development of more efficient methods of producing food.

One area that will receive more attention in the next few years is ecology. Climate change, pollution, and the destruction of natural ecosystems to feed a rapidly increasing human population are severe problems. We face two tasks: The first is to improve technology and our understanding about how things work in our biological world; the second, and probably the more difficult, is to educate people that their actions determine the kind of world in which future generations will live.

Another area that will receive much attention in the next few years is the relationship between genetic information and such diseases as Alzheimer's disease, stroke, arthritis, and cancer. These and many other diseases are caused by abnormal body chemistry, which is the result of hereditary characteristics. Curing hereditary diseases is a big job. It requires a thorough understanding of genetics and the manipulation of hereditary information in all of the trillions of cells of the organism.

It is the intent of science to learn what is going on by gathering facts objectively and identifying the most logical courses of action. It is also the role of science to identify cause-and-effect relationships and note their predictive value in ways that will improve the environment for all forms of life—including us. Scientists should also make suggestions to politicians and other policy makers about which courses of action are the most logical from a scientific point of view.

1.4 CONCEPT REVIEW

12. Describe three advances that have occurred as a result of biology.
13. List three mistakes that could have been avoided had we known more about living things.
14. What is biology?
15. List five characteristics of living things.
16. What is the difference between regulation and coordination?

Summary

The science of biology is the study of living things and how they interact with their surroundings. Science can be distinguished from nonscience by the kinds of laws and rules that are constructed to unify the body of knowledge. Science involves the continuous testing of rules and principles by the collection of new facts. In science, these rules are usually arrived at by using the scientific method—observation, questioning, the exploration of resources, hypothesis formation, and the testing of hypotheses. When general patterns are recognized, theories and laws are formulated. If a rule is not testable, or if no rule is used, it is not science. Pseudoscience uses scientific appearances to mislead.

Living things show the characteristics of (1) a unique structural organization, (2) metabolic processes, (3) generative processes, (4) responsive processes, and (5) control processes. Biology has been responsible for major advances in food production and health. The incorrect application of biological principles has sometimes led to the destruction of useful organisms and the introduction of harmful ones. Many biological advances have led to ethical dilemmas, which have not been resolved. In the future, biologists will study many things. Two areas that are certain to receive attention are ecology and the relationship between heredity and disease.

Key Terms

*Use the interactive flash cards on the **Concepts in Biology**, 14/e website to help you learn the meaning of these terms.*

atoms 16
biology 2
biosphere 16
cells 13
community 16
control group 6
control processes 15
controlled experiment 6
deductive reasoning (deduction) 7
dependent variable 6
ecosystem 16
emergent properties 17
energy 13
enzymes 15
experiment 6
experimental group 6
generative processes 14
homeostasis 15
hypothesis 5
independent variable 6
inductive reasoning (induction) 7
matter 13
metabolism 13
molecules 16
nutrients 13
observation 3
organ 16
organ system 16
organism 13
population 16
pseudoscience 11
responsive processes 14
science 2
scientific law 7
scientific method 3
theory 7
tissue 16
unique structural organization 13
variables 6

Basic Review

1. Which one of the following distinguishes science from nonscience?
   a. the collection of information
   b. the testing of a hypothesis
   c. the acceptance of the advice of experts
   d. information that never changes
2. A hypothesis must account for all available information, be logical, and be _____.
3. A scientific theory is
   a. a guess as to why things occur.
   b. always correct.
   c. a broad statement that ties together many facts.
   d. easily changed.
4. Pseudoscience is the use of the appearance of science to _____.
5. Economics is not considered a science because
   a. it does not have theories.
   b. it does not use facts.
   c. many economic predictions do not come true.
   d. economists do not form hypotheses.
6. Reproduction is
   a. a generative process.
   b. a responsive process.
   c. a control process.
   d. a metabolic process.
7. The smallest independent living unit is the _____.
8. The smallest unit that displays characteristics of life is the _____.
9. An understanding of the principles of biology will prevent policy makers from making mistakes. (T/F)
10. Three important advances in the control of infectious diseases are safe drinking water, safe food, and _____.
11. If data are able to be justified and are on target with other evidence, scientists say that these data are
    a. valid.
    b. reliable.
    c. expected.
    d. appropriate.
12. Which is not a basic assumption in science?
    a. There are specific causes for events observed in the natural world.
    b. There are general rules or patterns that can be used to describe what happens in nature.
    c. Events that occur only once probably have a single cause.
    d. The same fundamental rules of nature apply, regardless of where and when they occur.
13. A variable that changes in direct response to how another variable is manipulated is known as
    a. the dependent variable.
    b. the independent variable.
    c. the reliable variable.
    d. a hypothesis.
14. Features that result from the interaction of simple components when they form much more complex substances are called
    a. organizational properties.
    b. emergent properties.
    c. adaptive traits.
    d. evolutionary traits.

Answers
1. b 2. testable 3. c 4. mislead 5. c 6. a 7. organism 8. cell 9. F 10. vaccination 11. a 12. c 13. a 14. b

Thinking Critically

The Scientific Method and Climate Change
One important trait that all scientists should share is skepticism. They should consistently and constantly ask the question, "Are you sure that's right?" When considering the question of global warming, scientists might ask, "Is there a scientific basis that global warming is primarily due to greenhouse gases that are manmade?" The carbon dioxide content of the atmosphere is the highest it has been in millions of years and the rate of increase is unparalleled. What must scientists do to demonstrate a cause-and-effect relationship? As a scientist, how would you go about determining if this is simply a correlation and not a cause-and-effect relationship? How would you determine if there is a cause-and-effect relationship between the exponential increase in world human population in the last century and the increase in greenhouse gases? If the evidence ultimately points to a correlation, is it wise to ignore the potential risks associated with global warming?

CHAPTER 2

The Basics of Life

Chemistry

CFLs, A Bright Idea With Potential Health Problems

Lightbulbs cause for concern?

CHAPTER OUTLINE

Fluorescent lightbulbs were invented in the 1890s. However, it wasn't until the 1970s that compact fluorescent lights (CFLs), were developed as a spinoff of a world-wide oil shortage. The shortage stimulated research into ways of getting people to use the more energy-efficient bulbs. CFLs use only about 25% of the energy needed to produce the same amount of light as an incandescent bulb and last about 10 times longer. Replacing incandescent bulbs with CFLs will reduce the amount of fossil fuels burned to generate electricity, thus reducing greenhouse gases such as carbon dioxide. Ultimately, this will help to control global warming.

All fluorescent bulbs contain the element mercury, essential for their operation. Electricity vaporizes the mercury, causing it to emit UV light, which, in turn, causes other chemicals to light up; that is, they fluoresce. At first glance CFLs might seem to be a win-win situation (i.e., longer-lasting, lower-energy bulbs and less greenhouse gases). However, there is another problem.

Once released, certain bacteria can change mercury into the molecule methylmercury, which is highly toxic to the brain, heart, kidneys, lungs, and immune system, and is especially harmful to fetuses and children. In fact, about one in six children in the United States is at risk for learning disabilities from exposure to methylmercury. According to the EPA, the amount of mercury released from CFL bulbs can exceed U.S. federal guidelines for chronic exposure. As more CFLs are used, it may become essential to regulate their use and disposal.

- **What are elements and molecules?**
- **What should you do if one of these CFL bulbs breaks or wears out?**
- **Will you stop using such potentially dangerous products in favor of safer ones?**

Background Check

Concepts you should already know to get the most out of this chapter:
- The scientific method (chapter 1)
- Features that make something alive (chapter 1)
- The levels of biological organization (chapter 1)

2.1 Matter, Energy, and Life

All living things have the ability to use matter and energy to their advantage. Bees, bacteria, broccoli—in fact, all organisms—use energy to move about, respond to change, reproduce, make repairs and grow; in other words, to stay alive. **Energy** is the ability to do work or cause things to move. There are two general types of energy: *kinetic* and *potential*. A flying bird displays **kinetic energy,** or energy of motion. **Potential energy** is described as stored energy. When we talk about the energy in **chemicals,** substances used or produced in processes that involve changes in matter, we are talking about the potential energy in matter. **Matter** is anything that has mass[1] and takes up space. This energy has the potential to be converted to kinetic energy used to do life's work. Since energy has predictable properties, all organisms have similar ways of handling it.

There are five forms of energy, and each can be either kinetic or potential: (1) mechanical, (2) nuclear, (3) electrical, (4) radiant, and (5) chemical. All organisms interact in some way with these forms of energy. A race horse or a track athlete displays potential mechanical energy at the start line; the energy becomes kinetic mechanical energy when the athlete is running (figure 2.1). Nuclear energy is the form of energy from reactions involving the innermost part of matter, the atomic nucleus. In a nuclear power plant, nuclear energy is used to generate electrical energy. Electrical energy is associated with the movement of charged particles. All organisms use charged particles as a part of their metabolism. Radiant energy is most familiar as heat and visible light, but there are other forms as well, such as X-radiation and microwaves. Chemical energy is a kind of internal potential energy. It is stored in matter and can be released as kinetic energy when chemicals are changed from one form to another. For example, the burning of natural gas involves converting the chemical energy of gas into heat and light. A more controlled process releases the potential chemical energy from food in living systems, allowing them to carry out life's activities.

One of the predictable properties of energy is known as the **law of conservation of energy**, or the *first law of thermodynamics*. This law says that energy is not created or destroyed; but, energy can be converted from one form to another. For example, potential energy can become kinetic energy, and electrical energy can become heat energy as in a glowing CFL. However, the total energy in a system remains the same. Because living systems use energy, these systems are also subject to this law. As a result, when biologists study energy use in living organisms and ecosystems, they must account for all the energy.

FIGURE 2.1 Potential and Mechanical Energy
This horse has converted the potential energy in its food to the kinetic energy of motion. This is why, for centuries, horses have been called "hay burners."

Scientists define all living things as being composed of matter. There is no scientific evidence of a living thing composed of pure energy (despite what you might see on television), or being spiritual. To understand how organisms use these elements, you need to understand some basic principles about matter. **Chemistry** is the science concerned with the study of the composition, structure, and properties of matter and the changes it undergoes (figure 2.2).

2.1 CONCEPT REVIEW

1. What is potential energy?
2. Why is the first law of thermodynamics important to biology?

[1]Don't confuse the concepts of mass and weight. *Mass* refers to an amount of matter, whereas *weight* refers to the amount of force with which an object is attracted by gravity. Because gravity determines weight, your weight would be different on the Moon than it is on Earth, but your mass would be the same.

FIGURE 2.2 Biology and Chemistry Working Together
In order to understand living things, researchers must investigate both their structure and their function. At the core of modern biology is an understanding of molecular structure, including such molecules as DNA, the molecule of which genes are composed.

2.2 The Nature of Matter

The idea that substances are composed of very small particles goes back to early Greek philosophers. During the fifth century B.C., Democritus wrote that matter was empty space filled with tremendous numbers of tiny, indivisible particles called *atoms*. (The word *atom* is from the Greek word meaning uncuttable.)

Structure of the Atom

Recall from chapter 1 that atoms are the smallest units of matter that can exist alone. **Elements** are fundamental chemical substances made up of collections of only one kind of atom. For example, hydrogen (the most basic element), helium, lead, gold, potassium, and iron are all elements. There are over 100 elements. To understand how the atoms of various elements differ from each other, we need to look at the structure of atoms (How Science Works 2.1).

Atoms are constructed of three major subatomic particles: *neutrons, protons,* and *electrons*. A **neutron** is a heavy *subatomic* (units smaller than an atom) particle that does not have a charge; it is located in the central core of each atom. The central core is called the **atomic nucleus.** The mass of the atom is concentrated in the atomic nucleus. A **proton** is a heavy subatomic particle that has a positive charge; it is also located in the atomic nucleus. An **electron** is a light subatomic particle with a negative electrical charge that moves about outside the atomic nucleus in regions known as *energy levels* (figure 2.3). An **energy level** is a region of space surrounding the atomic nucleus that contains electrons with certain amounts of energy. The number of electrons an atom has determines the space, or volume, an atom takes up.

All the atoms of an element have the same number of protons. The number of protons determines the element's identity. For example, carbon always has 6 protons; no other element has that number. Oxygen always has 8 protons. The **atomic number** of an element is the number of protons in an atom of that element; therefore, each element has a unique atomic number. Because oxygen has 8 protons, its atomic number is 8. The mass of a proton is 1.67×10^{-24} grams. Because this is an extremely small mass and is awkward to express, 1 proton is said to have a mass of 1 **atomic mass unit** (abbreviated as AMU) (table 2.1).

Elements May Vary in Neutrons but Not Protons

Although all atoms of the same element have the same number of protons and electrons, they do not always have the same number of neutrons. In the case of oxygen, over 99% of the atoms have 8 neutrons, but others have more or fewer neutrons. Each atom of the same element with a different number of neutrons is called an **isotope** of that element. Since neutrons have a mass very similar to that of protons, isotopes that have more neutrons have a greater mass than those that have fewer neutrons.

Elements occur in nature as a mixture of isotopes. The **atomic weight** of an element is an average of all the isotopes present in a mixture in their normal proportions. For example, of all the hydrogen isotopes on Earth, 99.985% occur as an isotope without a neutron and 0.015% as an isotope with 1 neutron. There is a third isotope with 2 neutrons, and is even more rare. When the math is done to account for the relative amounts of these three isotopes of hydrogen, the atomic weight turns out to be 1.0079 AMU.

The sum of the number of protons and neutrons in the nucleus of an atom is called the **mass number.** Mass numbers are used to identify isotopes. The most common isotope of hydrogen has 1 proton and no neutrons. Thus, its mass number is 1 (1 proton + 0 neutrons = 1) also called protium. A hydrogen atom with 1 proton and 1 neutron has a mass number of 1 + 1, or 2, and is referred to as hydrogen-2, also called deuterium. A hydrogen atom with 1 proton and 2 neutrons has a mass number of 1 + 2, or 3, and is referred to as hydrogen-3, also called tritium (figure 2.4). All three isotopes of hydrogen are found on Earth, but the most frequently occurring has 1 AMU and is commonly called *hydrogen*. Most scientists use the term *hydrogen* in a generic sense (i.e., the term is not specific but might refer to any or all of these isotopes).

Subatomic Particles and Electrical Charge

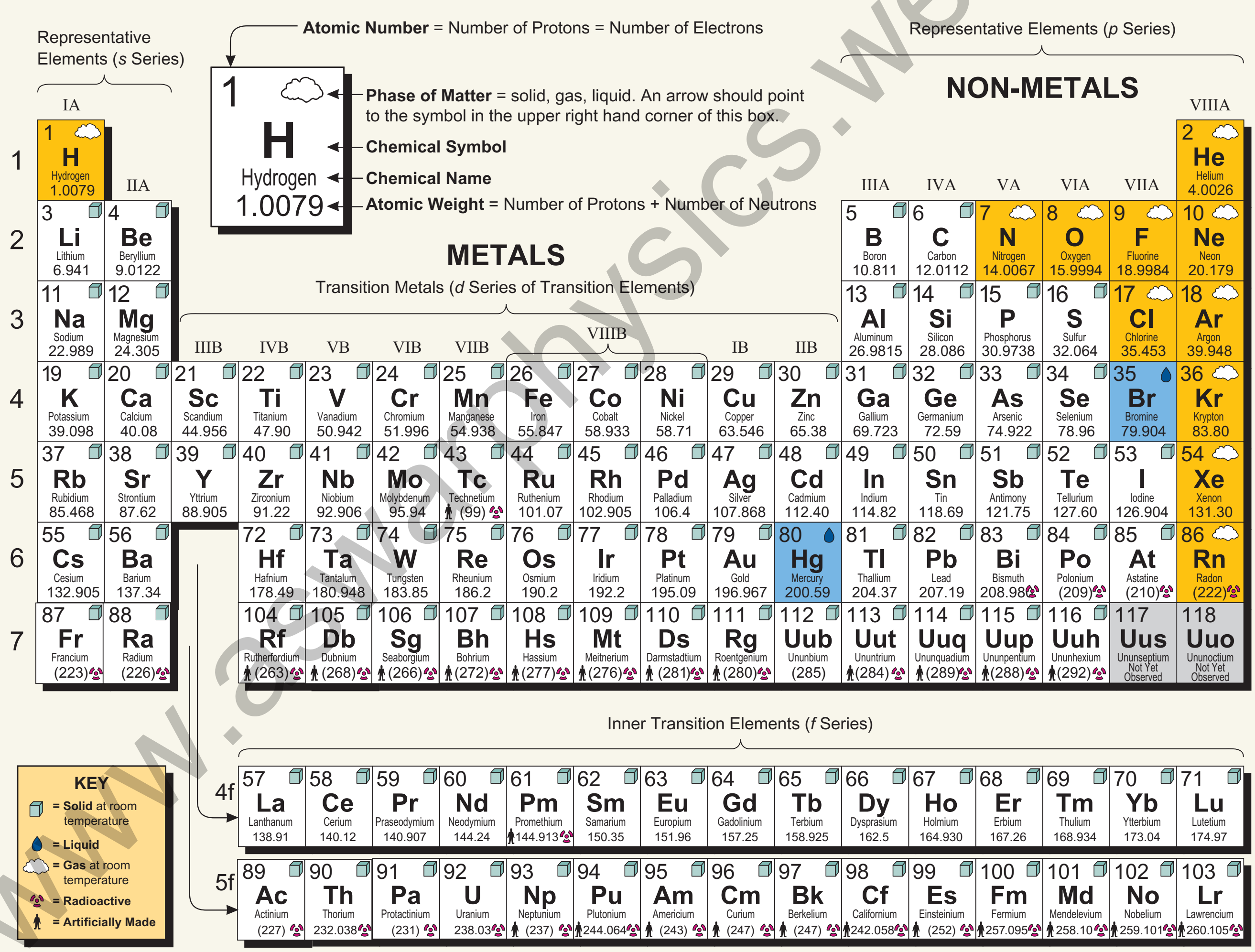
Subatomic particles were named to reflect their electrical charge. Protons have a positive (+) electrical charge. Neutrons are neutral because they lack an electrical charge (0). Electrons have a negative (−) electrical charge. Because positive and negative particles are attracted to one another, electrons are

HOW SCIENCE WORKS 2.1

The Periodic Table of the Elements

Traditionally, the elements have been represented in a shorthand form by letters called *chemical symbols*. The table that displays these symbols is called *periodic* because the properties of the elements recur periodically (at regular intervals) when the elements are listed in order of their size. The table has horizontal rows of elements called *periods*. The vertical columns are called *families*. The periods and families consist of squares, with each element having its own square in a specific location. This arrangement has a meaning, both about atomic structure and about chemical functions. The periods are numbered from 1 to 7 on the left side. Period 1, for example, has only two elements: H (hydrogen) and He (helium). Period 2 starts with Li (lithium) and ends with Ne (neon). The two rows at the bottom of the table are actually part of periods 6 and 7 (between atomic numbers 57 and 72, 89 and 104). They are moved so that the table is not so wide.

Families are identified with Roman numerals and letters at the top of each column. Family IIA, for example, begins with Be (beryllium) at the top and has Ra (radium) at the bottom. The A families are in sequence from left to right. The B families are not in sequence, and one group contains more elements than the others. The elements in vertical columns have similar arrangements of electrons, and that structure is responsible for the chemical properties of an element. Don't worry—you will not have to memorize the entire table. The 11 main elements comprising living things have the chemical symbols C, H, O, P, K, I, N, S, Ca, Fe, and Mg. (A mnemonic trick to help you remember them is CHOPKINS CaFé, Mighty good!).



Periodic Table of the Elements

The table provides information about all the known elements. Notice that the atomic weights of the elements increase as you read left to right along the periods. Reading top to bottom in a family gives you a glimpse of a group of elements that have similar chemical properties.