Concepts of

BIOLOGY

SECOND EDITION

Sylvia S. Mader

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CONCEPTS OF BIOLOGY, SECOND EDITION

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Brief Contents

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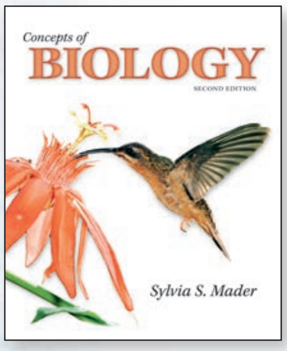
Preface: What Sets Mader Apart?

Focus on Key Biological Concepts



Biology—like no other discipline—uses concepts as a way to understand ourselves and the world we live in, and an understanding of biological principles should be within the grasp of all those who decide to study biology. Sylvia Mader is motivated by the desire to help science-shy students gain a conceptual understanding of biology.

Concepts of Biology was written not only to present the major concepts of biology clearly and concisely but also to show the relationships between the concepts at various levels of complexity.

Emphasis on biological concepts begins in the introductory chapter. In this edition, the first chapter discusses the scientific process and then proceeds to an overview of the five major concepts of biology. These key concepts have become the part titles for the book:

Part I: Organisms Are Composed of Cells
Part II: Genes Control the Traits of Organisms
Part III: Organisms Are Related and Adapted to Their Environment
Part IV: Plants Are Homeostatic
Part V: Animals Are Homeostatic
Part VI: Organisms Live in Ecosystems

Mader Writing Style

Well-known for its clarity and simplicity, the Mader writing style makes the content accessible to students. Mader's writing appeals to students because it meets them where they are and helps them understand the concepts with its clear "take-home messages" and relevant examples.

> *"This book uses everyday language to immerse the student into the world of science."* —Michael P. Mahan, *Armstrong Atlantic State University*

About the Author

Dr. Sylvia S. Mader has authored several nationally recognized biology texts published by McGraw-Hill. Educated at Bryn Mawr College, Harvard University, Tufts University, and Nova Southeastern University, she holds degrees in both Biology and Education. Over the years she has taught at University of Massachusetts, Lowell, Massachusetts Bay Community College, Suffolk University, and Nathan Mathew Seminars. Her ability to reach out to science-shy students led to the writing of her first text, *Inquiry into Life,* that is now in its thirteenth edition. Highly acclaimed for her crisp and entertaining writing style, her books have become models for others who write in the field of biology.

Although her writing schedule is always quite demanding, Dr. Mader enjoys taking time to visit and explore the various ecosystems of the biosphere. Her several trips to the Florida Everglades and Caribbean coral reefs resulted in talks she has given to various groups around the country. She has visited the tundra in Alaska, the taiga in the Canadian Rockies, the Sonoran Desert in Arizona, and tropical rain forests in South America and Australia. A photo safari to the Serengeti in Kenya resulted in a number of photographs for her texts. She was thrilled to think of walking in Darwin's steps when she journeyed to the Galápagos Islands with a group of biology educators. Dr. Mader was also a member of a group of biology educators who traveled to China to meet with their Chinese counterparts and exchange ideas about the teaching of modern-day biology.

For My Children —Sylvia Mader

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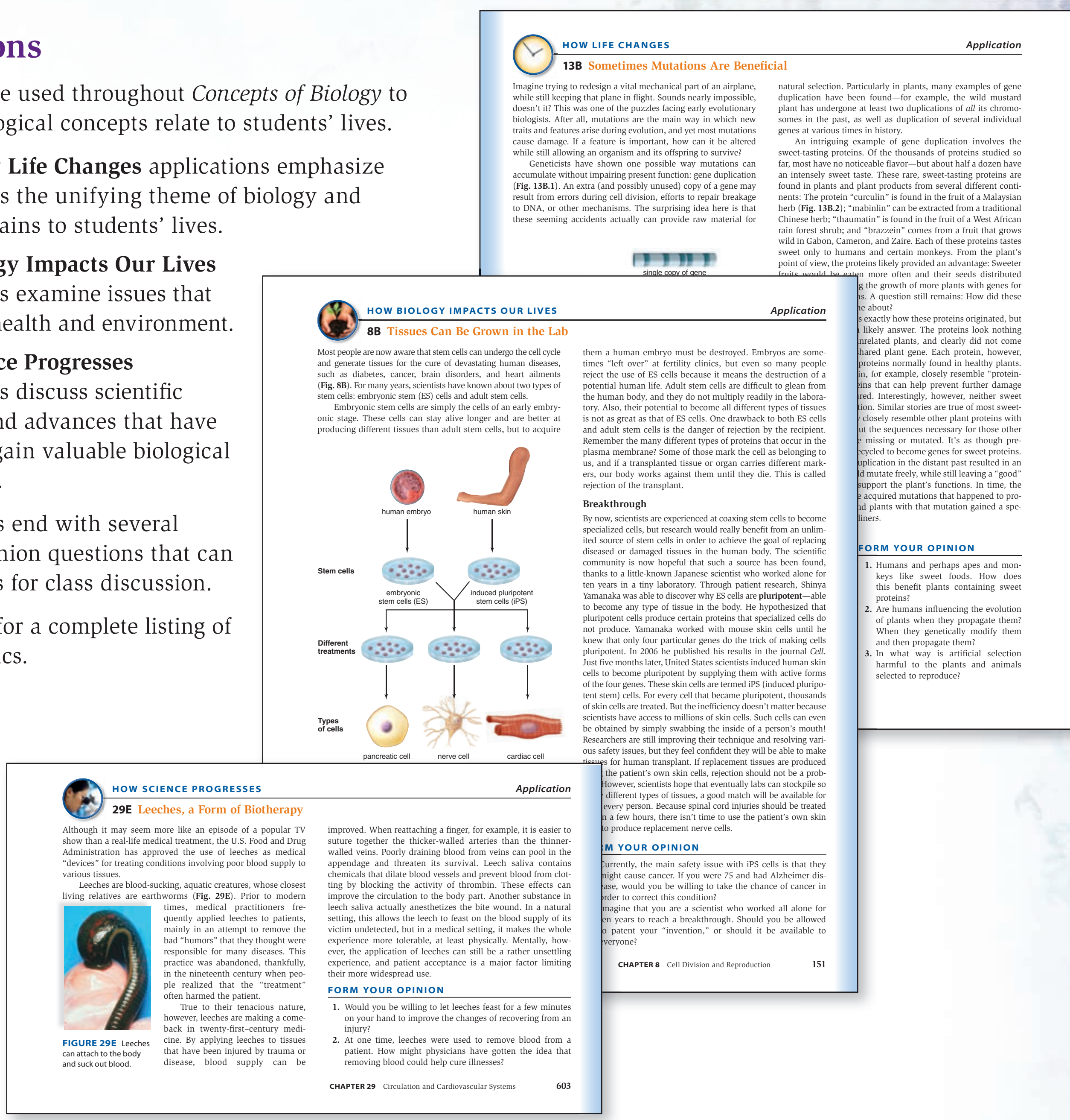
Applications

Applications are used throughout *Concepts of Biology* to show how biological concepts relate to students' lives.

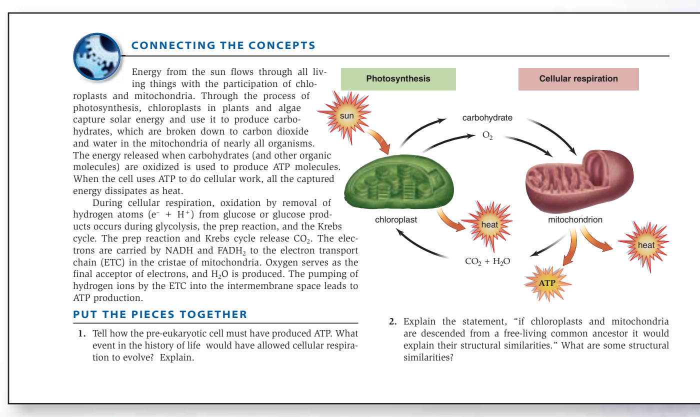
- ***NEW*** **How Life Changes** applications emphasize evolution as the unifying theme of biology and how it pertains to students' lives.
- **How Biology Impacts Our Lives** applications examine issues that affect our health and environment.
- **How Science Progresses** applications discuss scientific research and advances that have helped us gain valuable biological knowledge.

All applications end with several Form Your Opinion questions that can serve as a basis for class discussion.

See page xxvii for a complete listing of application topics.



In the second edition, the "**Connecting the Concepts**" feature appears at the end of each chapter. This feature includes narrative and several questions to help students understand how the concepts in the present chapter are related to one another and to those in other chapters.



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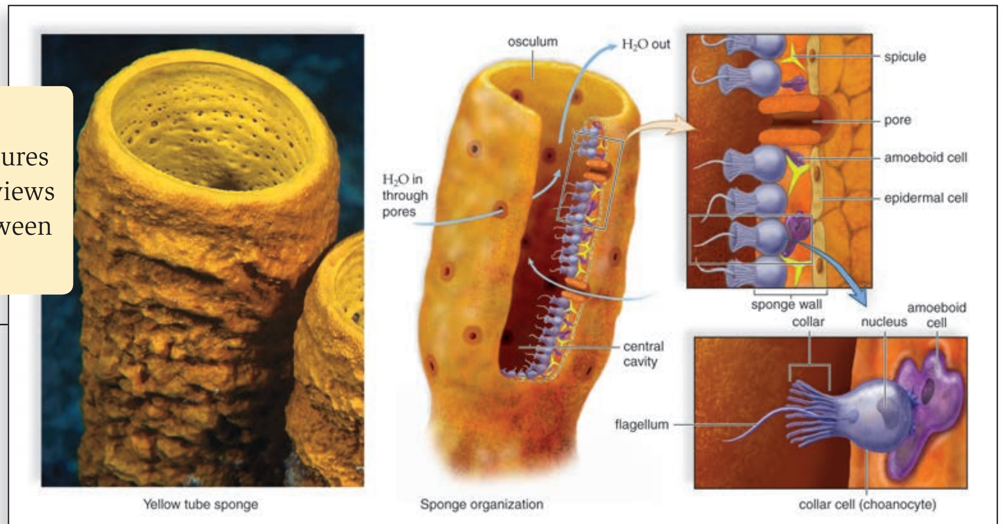
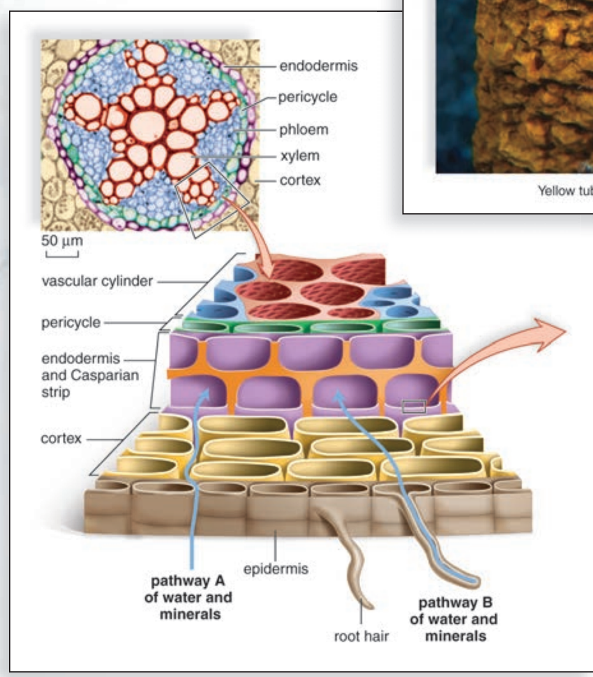
Instructional Art

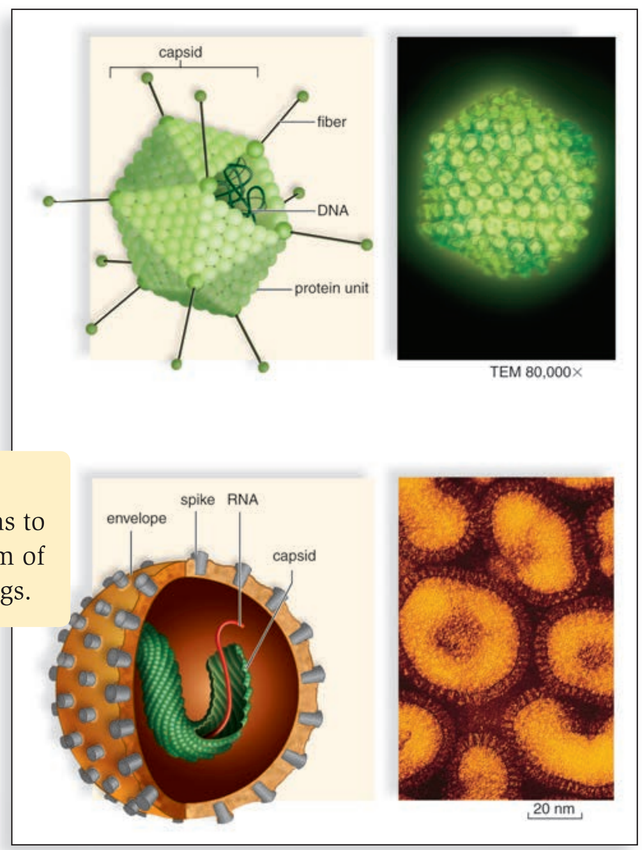
Outstanding photographs and dimensional illustrations, vibrantly colored, are featured throughout *Concepts of Biology*. Accuracy and instructional value were primary considerations in the development of each figure.



Multilevel Perspective

Illustrations depicting complex structures show macroscopic and microscopic views to help you see the relationships between increasingly detailed drawings.





Combination Art

Drawings of structures are paired with micrographs to give you the best of both perspectives: the realism of photos and the explanatory clarity of line drawings.

"The illustrations support the text strongly."
—Anju Sharma, Stevens Institute of Technology

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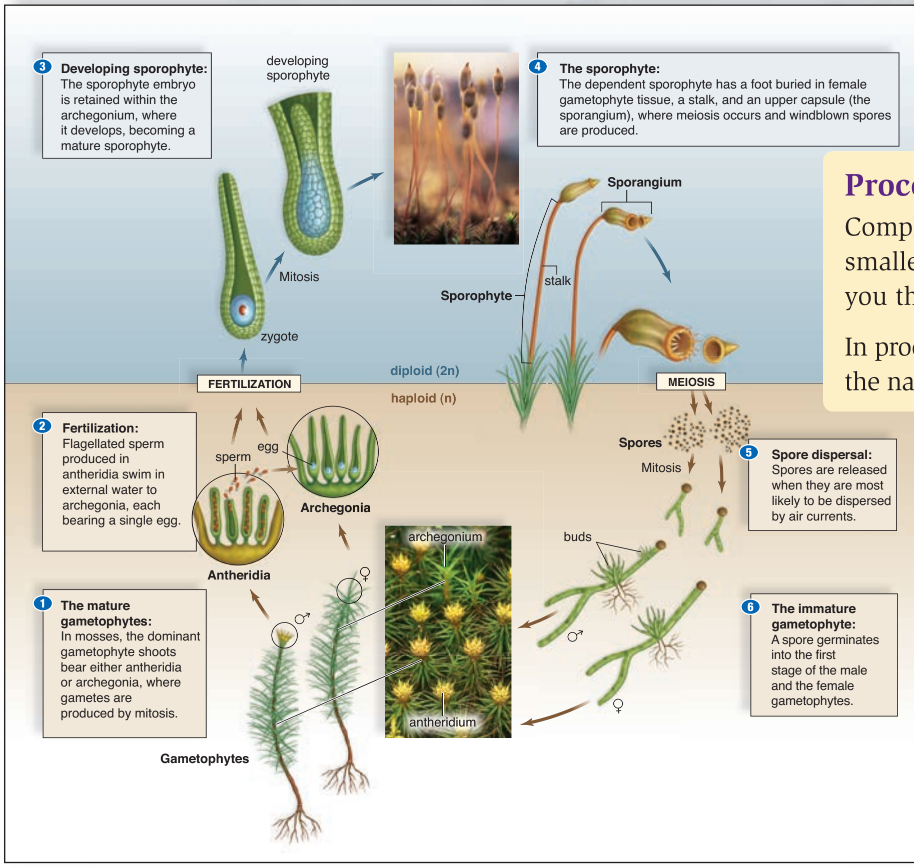


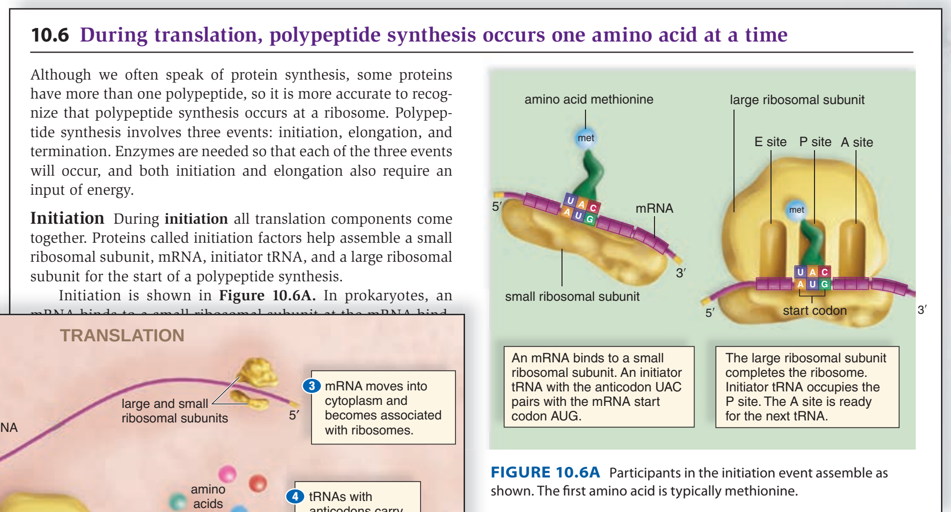
Process Figures

Complex processes are broken down into a series of smaller steps that are easy to follow. Numbers guide you through the process.

In process figures, numbered steps are coordinated with the narrative for an integrated approach to learning.

"The art, figures, and photos are excellent."

—Larry Szymczak,
Chicago State University



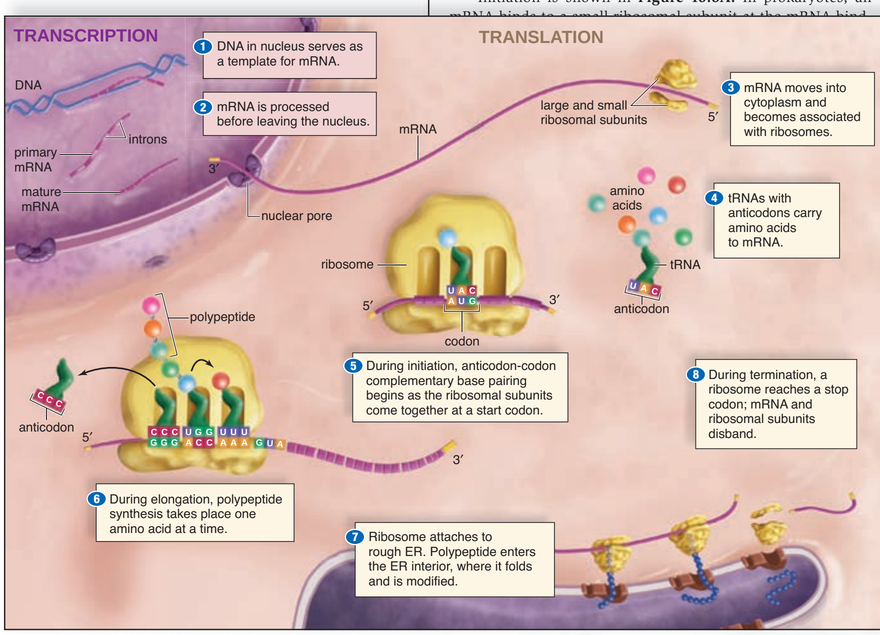
10.6 During translation, polypeptide synthesis occurs one amino acid at a time

Although we often speak of protein synthesis, some proteins have more than one polypeptide, so it is more accurate to recognize that polypeptide synthesis occurs at a ribosome. Polypeptide synthesis involves three events: initiation, elongation, and termination. Enzymes are needed so that each of the three events will occur, and both initiation and elongation also require an input of energy.

Initiation During **initiation** all translation components come together. Proteins called initiation factors help assemble a small ribosomal subunit, mRNA, initiator tRNA, and a large ribosomal subunit for the start of a polypeptide synthesis.

Initiation is shown in **Figure 10.6A.** In prokaryotes, an

FIGURE 10.6A Participants in the initiation event assemble as shown. The first amino acid is typically methionine.



Color Consistency

Consistent use of color organizes information and clarifies concepts.

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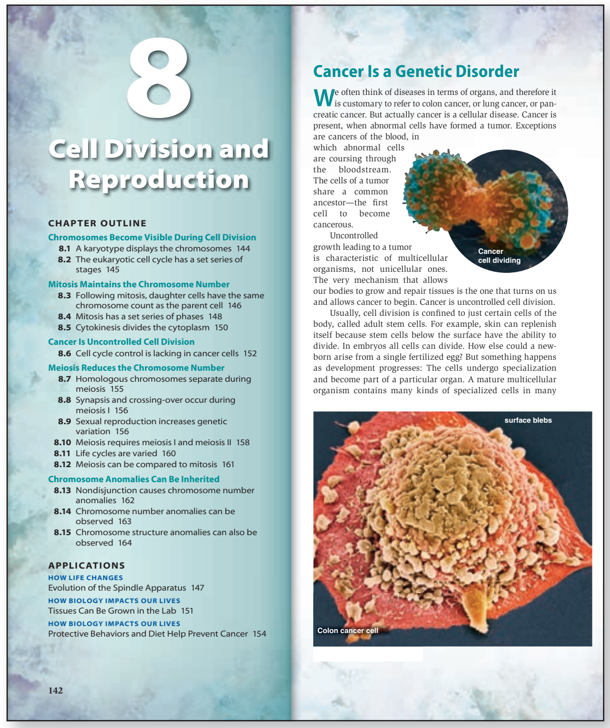
The Mader Learning System

Each chapter features numerous learning aids that were carefully developed to help students grasp challenging concepts.

A **Chapter Outline** lists the chapter concepts and the topics (numbered) that will be discussed in the chapter. **Applications** are also listed.



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Cell Division and Reproduction

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HOW BIOLOGY IMPACTS OUR LIVES
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HOW BIOLOGY IMPACTS OUR LIVES
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Cancer Is a Genetic Disorder

We often think of diseases in terms of organs, and therefore it is customary to refer to colon cancer, or lung cancer, or pancreatic cancer. But actually cancer is a cellular disease. Cancer is present, when abnormal cells have formed a tumor. Exceptions are cancers of the blood, in which abnormal cells are coursing through the bloodstream. The cells of a tumor share a common ancestor—the first cell to become cancerous.

Uncontrolled growth leading to a tumor is characteristic of multicellular organisms, not unicellular ones. The very mechanism that allows our bodies to grow and repair tissues is the one that turns on us and allows cancer to begin. Cancer is uncontrolled cell division.

Usually, cell division is confined to just certain cells of the body, called adult stem cells. For example, skin can replenish itself because stem cells below the surface have the ability to divide. In embryos all cells can divide. How else could a newborn arise from a single fertilized egg? But something happens as development progresses: The cells undergo specialization and become part of a particular organ. A mature multicellular organism contains many kinds of specialized cells in many

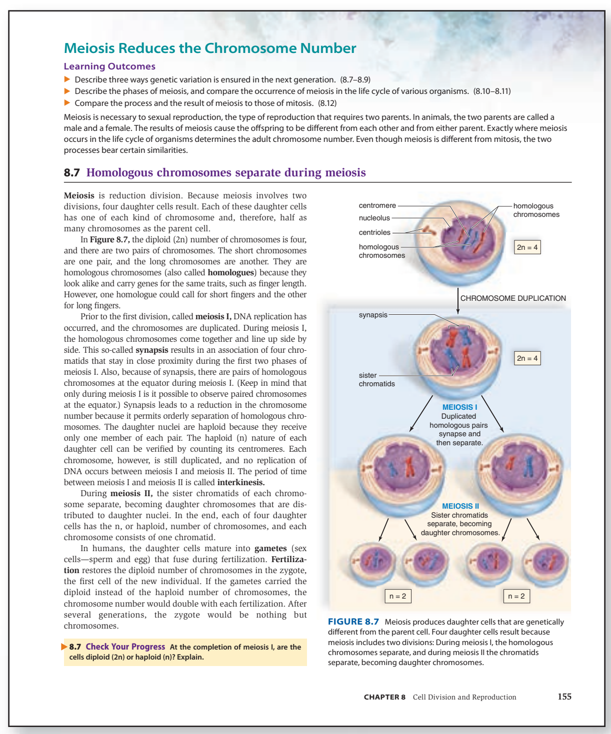
"The organization of the text around the major theories of Biology is a wise path to follow; it integrates the chapters into themes and points out the development of a theory. . . .
—Paul E. Wanda, Southern Illinois University, Edwardsville

Learning Outcomes are listed at the start of each major section to provide students with an overview of what they are to know.

Section Introductions orient students to concepts in a short, easy-to-understand manner.

Figure Legends have been expanded in this edition to reinforce the discussion and to improve student learning.

Check Your Progress questions at the end of each section help students assess and/or apply their understanding of a concept.



Meiosis Reduces the Chromosome Number

Learning Outcomes
- Describe three ways genetic variation is ensured in the next generation. (8.7–8.9)
- Describe the phases of meiosis, and compare the occurrence of meiosis in the life cycle of various organisms. (8.10–8.11)
- Compare the process and the result of meiosis to those of mitosis. (8.12)

Meiosis is necessary to sexual reproduction, the type of reproduction that requires two parents. In animals, the two parents are called a male and a female. The results of meiosis cause the offspring to be different from each other and from either parent. Exactly where meiosis occurs in the life cycle of organisms determines the adult chromosome number. Even though meiosis is different from mitosis, the two processes bear certain similarities.

8.7 Homologous chromosomes separate during meiosis

Meiosis is reduction division. Because meiosis involves two divisions, four daughter cells result. Each of these daughter cells has one of each kind of chromosome and, therefore, half as many chromosomes as the parent cell.

In **Figure 8.7,** the diploid (2n) number of chromosomes is four, and there are two pairs of chromosomes. The short chromosomes are one pair, and the long chromosomes are another. They are homologous chromosomes (also called **homologues**) because they look alike and carry genes for the same traits, such as finger length. However, one homologue could call for short fingers and the other for long fingers.

Prior to the first division, called **meiosis I,** DNA replication has occurred, and the chromosomes are duplicated. During meiosis I, the homologous chromosomes come together and line up side by side. This so-called **synapsis** results in an association of four chromatids that stay in close proximity during the first two phases of meiosis I. Also, because of synapsis, there are pairs of homologous chromosomes at the equator during meiosis I. (Keep in mind that only during meiosis I is it possible to observe paired chromosomes at the equator.) Synapsis leads to a reduction in the chromosome number because it permits orderly separation of homologous chromosomes. The daughter nuclei are haploid because they receive only one member of each pair. The haploid (n) nature of each daughter cell can be verified by counting its centromeres. Each chromosome, however, is still duplicated, and no replication of DNA occurs between meiosis I and meiosis II. The period of time between meiosis I and meiosis II is called **interkinesis.**

During **meiosis II,** the sister chromatids of each chromosome separate, becoming daughter chromosomes that are distributed to daughter nuclei. In the end, each of four daughter cells has the n, or haploid, number of chromosomes, and each chromosome consists of one chromatid.

In humans, the daughter cells mature into **gametes** (sex cells—sperm and egg) that fuse during fertilization. **Fertilization** restores the diploid number of chromosomes in the zygote, the first cell of the new individual. If the gametes carried the diploid instead of the haploid number of chromosomes, the chromosome number would double with each fertilization. After several generations, the zygote would be nothing but chromosomes.

8.7 Check Your Progress At the completion of meiosis I, are the cells diploid (2n) or haploid (n)? Explain.

FIGURE 8.7 Meiosis produces daughter cells that are genetically different from the parent cell. Four daughter cells result because meiosis includes two divisions: During meiosis I, the homologous chromosomes separate, and during meiosis II the chromatids separate, becoming daughter chromosomes.

CHAPTER 8 Cell Division and Reproduction 155

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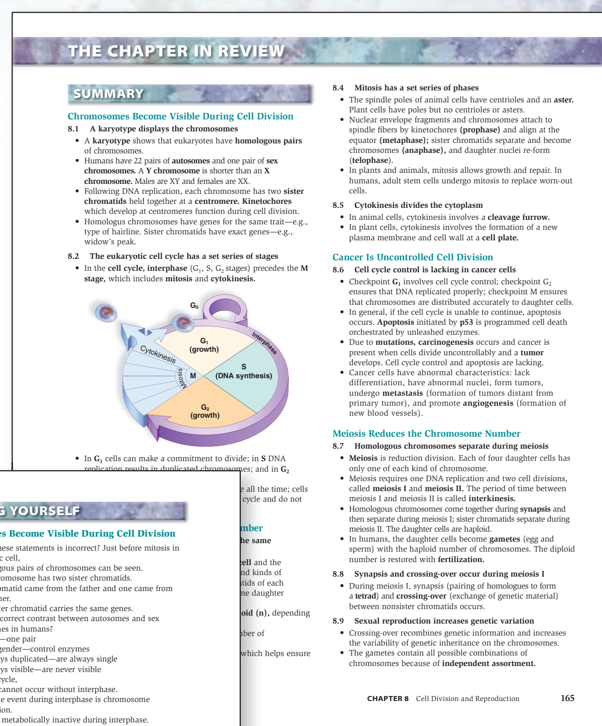
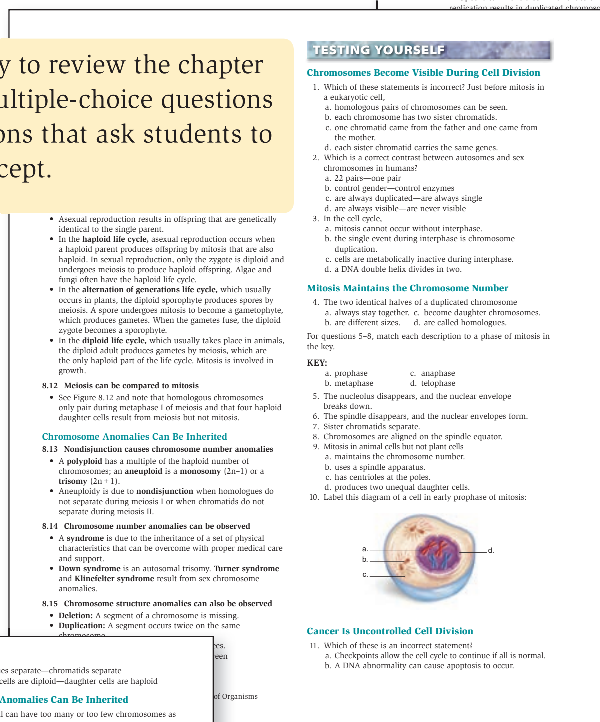
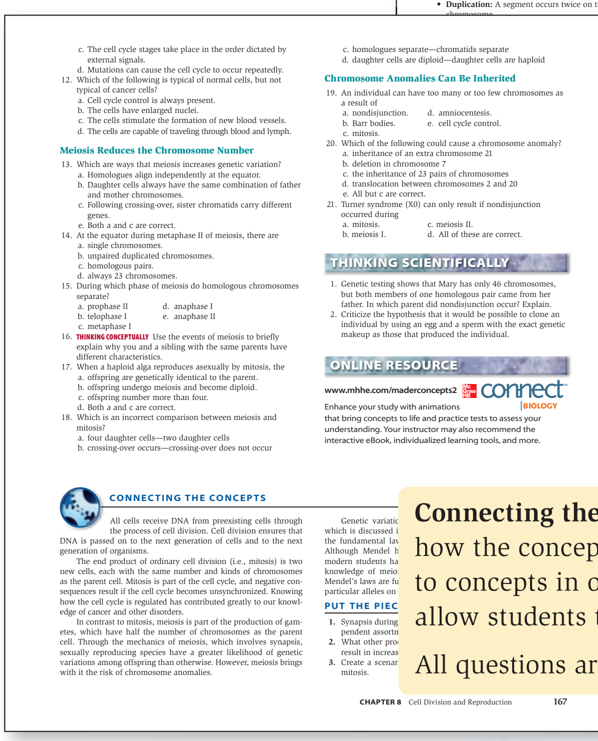
A bulleted and illustrated **Summary** is organized according to the chapter concepts and helps students review the chapter. New to this edition, the boldface terms are included in the summary as an aid to learning these terms in a nonthreatening way.



Testing Yourself offers another way to review the chapter concepts. Included are objective multiple-choice questions and Thinking Conceptually questions that ask students to apply their understanding of a concept.



"It would be fun to teach and learn using this book."
—Brian W. Schwartz,
Columbus State University



Thinking Scientifically questions end the chapter. These questions apply directly to the chapter and ask students to design an experiment or explain some part of a hypothetical experiment.

Connecting the Concepts feature at the end of the chapter shows how the concepts of the chapter are related, and how they relate to concepts in other chapters. "Put the Pieces Together" questions allow students to test their reasoning ability.

All questions are answered in the Appendix.

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What's New to the Second Edition of *Concepts of Biology*

The second edition of *Concepts of Biology* continues to present concepts clearly and make biology relevant through the use of excellent writing, instructional art, and effective pedagogical tools. This new edition also includes

- **Significant content changes,** as outlined below.
- **Enhanced evolutionary coverage,** including extensive updates to the evolution chapters and the addition of *How Life Changes* applications.
- **Media integration,** including a robust set of teaching and learning tools through McGraw-Hill's Connect™ Biology.

Content Changes

Chapter 1, Biology, the Study of Life, was rewritten. It begins with a discussion of the scientific process and proceeds to an overview of the major concepts of biology (cell theory, gene theory, theory of evolution, theory of homeostasis, and theory of ecosystems). Basic evolutionary principles are presented, and a depiction of the Tree of Life introduces the three domains of life and the various types of eukaryotes.

Part I: Organisms Are Composed of Cells **Chapter 4,** Structure and Function of Cells, presents an improved discussion on cell structure and two new tables. Table 4.4 summarizes the differences between plant and animal cells, and Table 4.16 summarizes the eukaryotic cell structures and their functions. A new figure (Fig. 4.13) stresses that plant cells have both mitochondria and chloroplasts. **Chapter 5,** Dynamic Activities of Cells, includes sharpened energy transformation analogies with references to everyday occurrences (see Figs. 5.1, 5.3B, and 5.5A). Cell communication was stressed with the addition of a new section (Section 5.13). **Chapter 7,** Pathways of Photosynthesis, provides an improved discussion of mitochondrial structure. Changes to Figures 7.4 and 7.7B offer views from the whole cell to particles on the mitochondrial inner membrane.

Part II: Genes Control the Traits of Organisms All chapters in Part II were rewritten to present concepts at a student-friendly pace, and thereby increase student interest and learning. Modern genetics has been updated. **Chapter 11,** Regulation of Gene Activity, is now at an appropriate level and explains how humans can make do with far fewer protein-coding genes than expected. **Chapter 12,** Biotechnology and Genomics, offers a short, but complete, discussion of the human genome, including the several types of DNA sequences that are not protein-coding genes.

Part III: Organisms Are Related and Adapted to Their Environment The evolution chapters include extensive revisions. **Chapter 14,** Speciation and Evolution, now includes real-life examples of various processes that can cause speciation. The influence of regulatory genes during development helps explain how species can share the same genes but have different phenotypes. **Chapter 15,** The Evolutionary History of Life on Earth, will help instructors introduce their students to cladistics. It explains the rationale behind the replacement of Linnean classification with that of cladistics in a way that allows instructors to be up-to-date, while not overburdening beginning students. **Chapter 17,** Evolution of Protists, introduces a new evolutionary tree of protists based on molecular data. The chapter still emphasizes the biological and ecological relevance of each type of protist. **Chapter 18,** Evolution of Plants and Fungi, employs a new evolutionary tree based in part on molecular data. Land plants and stoneworts, which are charophytes, share a common green algal ancestor. All land plants protect the embryo, and thereafter each of four innovations can be associated with a particular group of land plants. **Chapter 19,** Evolution of Animals, introduces the new evolutionary tree of animals based on molecular and developmental data. The biology of each group is discussed as before. **Chapter 20,** Evolution of Humans, was rewritten to include a description and importance of the newly studied fossil *Ardipithicus ramidus.*

Part IV: Plants Are Homeostatic **Chapter 21,** Plant Organization and Homeostasis, includes a rewrite of Section 21.1 to better explain the overall organization of a plant and the functions of roots, stems, and leaves. This supports a rewrite of Section 21.8 which discusses more authoritatively how plants maintain homeostasis. **Chapter 22,** Transport and Nutrition in Plants, includes a reorganization of Sections 22.4 and 22.6 to increase student understanding of phloem structure and function, and root structure and function. **Chapter 24,** Reproduction in Plants, was reorganized and rewritten to better present an overview of the flowering plant life cycle and place it in an evolutionary context.

Part V: Animals Are Homeostatic **Chapter 26,** Coordination by Neural Signaling, was reorganized and begins with an overview of the structure and function of the human nervous system, before comparing this system to that of other animals. **Chapter 30,** Lymph Transport and Immunity, includes an updated and rewritten discussion of immunity to be consistent with current immunity literature. **Chapter 32,** Gas Exchange and Transport in Animals, provides a discussion

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on the transport of gases and exchange of gases that is more clearly related to external and internal respiration. **Chapter 33,** Osmoregulation and Excretion, places osmoregulation in fishes versus terrestrial animals in an evolutionary context, showing that physiology in other animals is relevant to understanding kidney function in humans. **Chapter 34,** Coordination by Hormone Signaling, was expanded to better stress the role of negative feedback in hormonal control and the role of the pituitary gland in humans.

Part VI: Organisms Live in Ecosystems **Chapter 36,** Population Ecology, was reorganized to show the relationship between growth rate, survivorship, and the age structure of a population. These same principles are more clearly applied to the human population at the end of the chapter. **Chapter 37,** Behavioral Ecology, better applies the genetic control of behavior and the process of sexual selection to behavior in general and to human behavior in particular. **Chapter 38,** Community and Ecosystem Ecology, includes an updated discussion of ecological succession to clearly show the difference between primary and secondary succession. **Chapter 40,** Conservation Biology, includes a new section on sustainability. This section stresses that it is not too late for humans to plan for and bring about sustainability so that future generations will have a comparable standard of living to our own.

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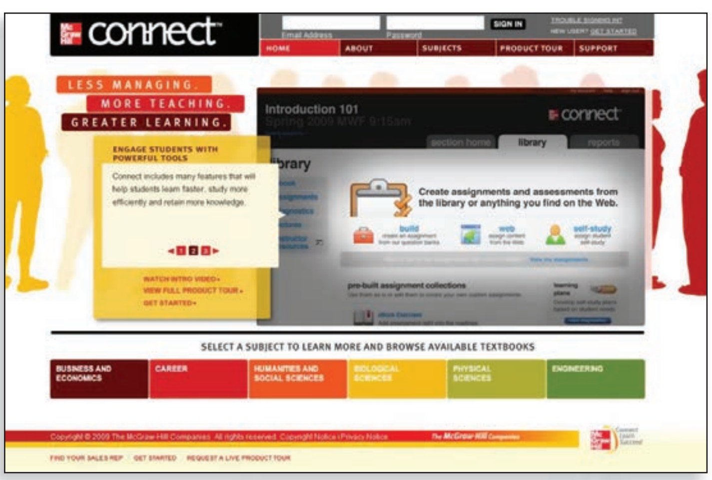

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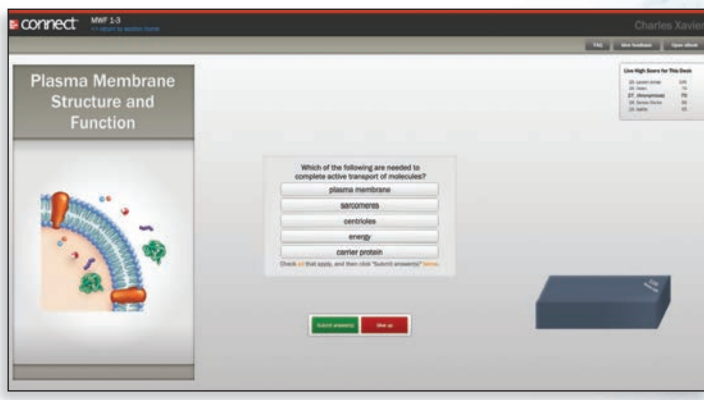
Visit the site below for a demonstration.

www.mhlearnsmart.com



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Ch02	Ch. 2 Enhanced Image PPTs (9,907 KB)	Ch. 2 Lecture Animation PPTs (6,012 KB)	Ch. 2 Animation PPTs (6,794 KB)	Ch. 2 Labeled Images (15,054 KB)	Ch. 2 Base Images (8,805 KB)
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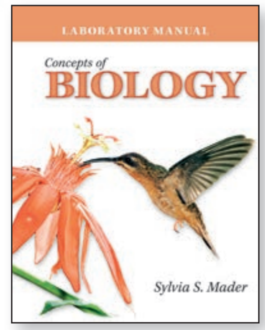

The *Concepts of Biology Laboratory Manual* is written by Dr. Sylvia Mader. With few exceptions, each chapter in the text has an accompanying laboratory exercise in the manual. Every laboratory has been written to help students learn the fundamental concepts of biology and the specific content of the chapter to which the lab relates, as well as gain a better understanding of the scientific method.

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www.mhhe.com/maderconcepts2

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This process is designed to provide a broad, comprehensive spectrum of feedback for refinement and innovation of our learning tools, for both student and instructor. The 360° Development Process includes market research, content reviews, course- and product-specific symposia, accuracy checks, and art reviews. We appreciate the expertise of the many individuals involved in this process.

Contributors

Lisa Bonneau
Metropolitan Community College—Blue River
Jane Caldwell
Washington and Jefferson College
Susan Fisher
The Ohio State University
Phil Gibson
University of Oklahoma
Jeffrey Isaacson
Nebraska Wesleyan University
Shelley Jansky
University of Wisconsin—Stevens Point
Michael Thompson
Middle Tennessee State University

Ancillary Authors

Instructor's Manual
Kimberly Lyle-Ippolito
Anderson University

Test Bank
Jo Wen Wu
Fullerton College
Stephanie Songer
North Georgia College and State University

Lecture Outlines
Brenda Leady
University of Toledo

FlexArt
Sharon Thoma
University of Wisconsin—Madison

Media Correlations
Jennifer Burtwistle
Northeast Community College

Second Edition Reviewers

Muhammad Ashraf Mian
Rust College
Ellen Baker
Santa Monica College
Mary K. Beals
Southern University A&M
Cheryl Boice
Lake City Community College
Lisa Bryant
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Tarrant County College—Northeast
Marc DalPonte
Lake Land College
Tammy D. Dennis
Bishop State Community College
Greg Farley
Chesapeake College
Patrick Galliart
North Iowa Area Community College
Tammy R.Gamza
Arkansas State University—Beebe
Joyce Ache Gana
Chicago State University
Michaela Gazdik
Ferrum College
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Moraine Valley Community College
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San Jacinto College—Central
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Salt Lake Community College
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St. Louis Community College at Meramec
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Winston Salem State University
Barbara Hasek
Baton Rouge Community College
Jennifer A. Herzog
Herkimer County Community College
Ross S. Johnson
Chicago State University
Judith Kjellman
Yakima Valley Community College
Dale Lambert
Tarrant County College—Northeast
Yevgeniya Lapik
Harry S. Truman College
David Loring
Johnson County Community College
John McCastlain
ASU—Heber Springs

Melissa Meador
Arkansas State University—Beebe
Beth Miller
Pulaski Technological College
Linda Moore
Georgia Military College
Scott Murdoch
Moraine Valley Community College
Rajkumar Nathaniel
Nicholls State University
Philip Pepe
Phoenix College
Crystal Pietrowicz
Southern Maine Community College
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Nassau Community College
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Ferrum College
Ramona Rice
Georgia Military College
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Northwest Florida State College
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West Liberty State College
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Chicago State University
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Triton College
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Montgomery College
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SUNY/Westchester Community College
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Ozarks Technical Community College
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Montclair State University
Elizabeth Vise
Tarrant County College—Northeast Campus
Ryan Wagner
Millersville University of Pennsylvania
Joe David White
Holmes Community College
Daniel Williams
Winston-Salem State University
Mary Wisgirda
San Jacinto College
Michelle Zurawski
Moraine Valley Community College

First Edition Reviewers

Emily Allen
Gloucester County College
Kathy Pace Ames
Illinois Central College
Jason E. Arnold
Hopkinsville Community College
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North Carolina A&T State University
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Broome Community College
Natasa Kesler
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Dennis J. Kitz
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Houston Community College, Northwest
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Lander University
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Seattle Central Community College
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Golden West College
Thomas G. Lammers
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Washburn University
Peggy Lepley
Cincinnati State Technical and Community College
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Lander University
Janice B. Lynn
Auburn University, Montgomery
Michael P. Mahan
Armstrong Atlantic State University
Elizabeth A. Mays
Illinois Central College
TD Maze
Lander University
Jennifer Richter Maze
Lander University
Tiffany B. McFalls
Southeastern Louisiana University
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Cardinal Stritch University
Thomas H. Milton
Richard Bland College
Jerry W. Mimms
University of Central Arkansas
Jeanne Mitchell
Truman State University
Brenda Moore
Truman State University
Allan D. Nelson
Tarleton State University
Jonas E. Okeagu
Fayetteville State University
Nathan Okia
Auburn University—Montgomery
Frank H. Osborne
Kean University
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Eastern Oregon University
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Somerset Community College
Jason F. Schreer
State University of New York at Potsdam
Gillian P. Schultz
Seattle Central Community College
Brian W. Schwartz
Columbus State University
Anju Sharma
Stevens Institute of Technology
Brian E. Smith
Black Hills State University
Maryann Smith
Brookdale Community College
Larry Szymczak
Chicago State University
Christopher Tabit
University of West Georgia
Season R. Thomson
Germanna Community College
Randall L. Tracy
Worcester State College
Anh-Hue Tu
Georgia Southwestern State University
George Veomett
University of Nebraska–Lincoln
Jyoti R. Wagle
Houston Community College System, Central
Ryan L. Wagner
Millersville University of Pennsylvania
Paul E. Wanda
Southern Illinois University, Edwardsville
Kelly J. Wessell
Tompkins Cortland Community College
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Riverside Community College
Bob Wise
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Every year McGraw-Hill conducts several General Biology Symposia, which are attended by instructors from across the country. These events are an opportunity for editors from McGraw-Hill to gather information about the needs and challenges of instructors teaching nonmajor-level biology courses. It also offers a forum for the attendees to exchange ideas and experiences with colleagues they might not have otherwise met. The feedback we have received has been invaluable, and has contributed to the development of *Concepts of Biology* and its ancillaries.

Norris Armstrong
University of Georgia
David Bachoon
Georgia College and State University
Sarah Bales
Moraine Valley Community College
Lisa Bellows
North Central Texas College
Joressia Beyer
John Tyler Community College
James Bidlack
University of Central Oklahoma
Mark Bloom
Texas Christian University
Paul Bologna
Montclair University
Bradford Boyer
Suffolk County Community College
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Henry Ford Community College
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University of Georgia
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Virginia Polytechnic Institute
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Greenville Technical College
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South Texas College
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Emporia State University
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Itawamba Community College
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Community College of Southern Nevada
Julie Sutherland
College of DuPage
Bill Trayler
California State University–Fresno
Linda Tyson
Santa Fe Community College
Eileen Underwood
Bowling Green State University
Heather Vance-Chalcraft
East Carolina University
Marty Vaughan
IUPUI–Indianapolis
Paul Verrell
Washington State University
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Applications

HOW BIOLOGY IMPACTS OUR LIVES

HOW LIFE CHANGES

HOW SCIENCE PROGRESSES

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1

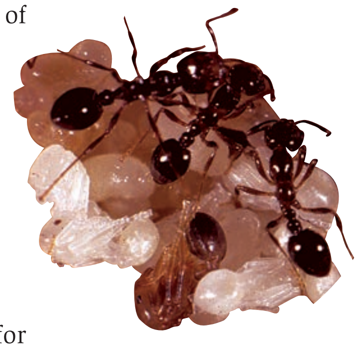
Biology, the Study of Life

CHAPTER OUTLINE

APPLICATIONS

Fire Ants Have a Good Defense

Fire ants have a red to reddish-brown color, but even so, they most likely take their name from the ability to STING. Their stinger protrudes from the rear, but in a split second, they can grab a person's skin with their mandibles and position the stinger between their legs to sting from the front. The stinger injects a toxin into the tiny wound, and the result is a burning sensation. The next day, the person has a white pustule at the site of the sting. The success of this defense mechanism is clear because most animals, including humans, try to stay away from bees, wasps, and ants—and any other animal that can sting.



Living usually in an open, grassy area, fire ants sting in order to defend their home, which is a mound of soil that they have removed from subterranean tunnels. They use the tunnels to safely travel far afield when searching for food, which they bring back to their nest mates. The queen and many worker ants live in chambers within the mound or slightly below it. The queen is much larger

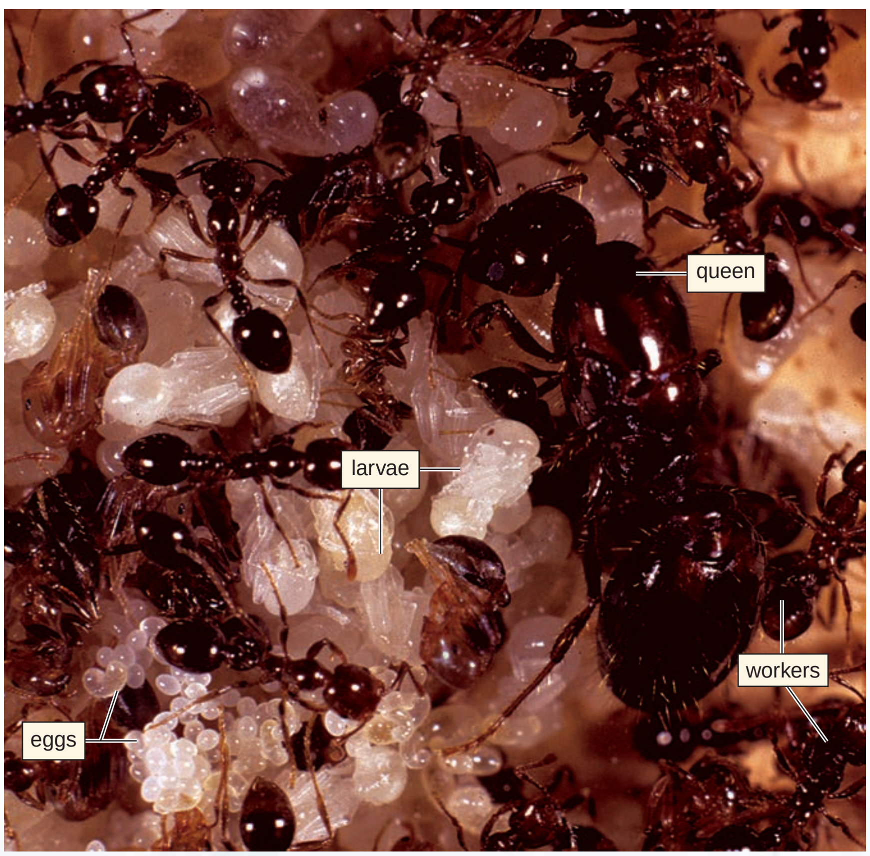
Fire ant mound

than the other members of the colony, and she has only one purpose: to produce many thousands of small, white eggs. The eggs develop into cream-colored, grublike larvae, which are lavishly tended by worker ants to keep them clean and well fed. When the larvae become encased by a hard covering, they are pupae. Inside a pupa, an amazing transformation takes place, and eventually an adult ant breaks out. Most of these adults are worker ants, but in the spring, a few are winged "sexuals," which are male and female ants with the ability to reproduce. The sexuals remain inside the colony with nothing to do until the weather is cooperative enough for them to fly skyward to mate. A few of the fertilized females manage to survive the perils of an outside existence long enough to start another colony.

All of the ants in a colony have the same mother, namely the queen ant who produces the eggs. The workers are sterile, closely related sister ants. Because of their genetic relationship, we can view the members of a colony as a superorganism. The queen serves as the reproductive system, while the workers serve as the digestive and urinary systems, as well as all the other systems that keep the superorganism functioning. What fosters cooperation between the members of the superorganism? The answer is chemicals, pheromones secreted externally that influence the behavior and even the development of the ants. Fire ants, like other ants, produce several different pheromones that send messages when released into the air. The message could be "food is available" or "be alert for possible danger." The queen even releases pheromones that cause workers to attend her.

Why does it work, in a biological sense, for these sisters to spend their lives slavishly working away, raising more sterile sisters and defending the colony with little regard for their own safety? It works because the few sexual females that survive their temporary existence on the outside pass the colony's joint genes on to future generations in new and different places. Any social system that allows an organism to pass on its genes is a successful one from an evolutionary point of view.

In this chapter, we will first learn how the scientific understanding of life progresses by making observations and doing experiments. Then we will examine the five scientific theories around which this book is organized. The theory of evolution is examined in particular detail because it is the unifying theory of biology.



A fire ant colony (*Solenopsis invicta*).

Pustules caused by fire ants.

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Science Helps Us Understand the Natural World

Learning Outcomes

- Divide the scientific method into four steps and discuss each one. (1.1)
- Describe an experimental design that contains a control group. (1.2)

Biology is the scientific study of life, and therefore it is appropriate for us to first consider what we mean by science. Science is a way of making sense of the natural world around us. Religion, aesthetics, and ethics are all ways that human beings can find order in the natural world. Science, unlike these other ways of knowing is testable. It also leads to improved technology and is responsible for the modern ways in which we travel, communicate, farm, build our houses, and even how we conduct science.

1.1 Scientists use a preferred method

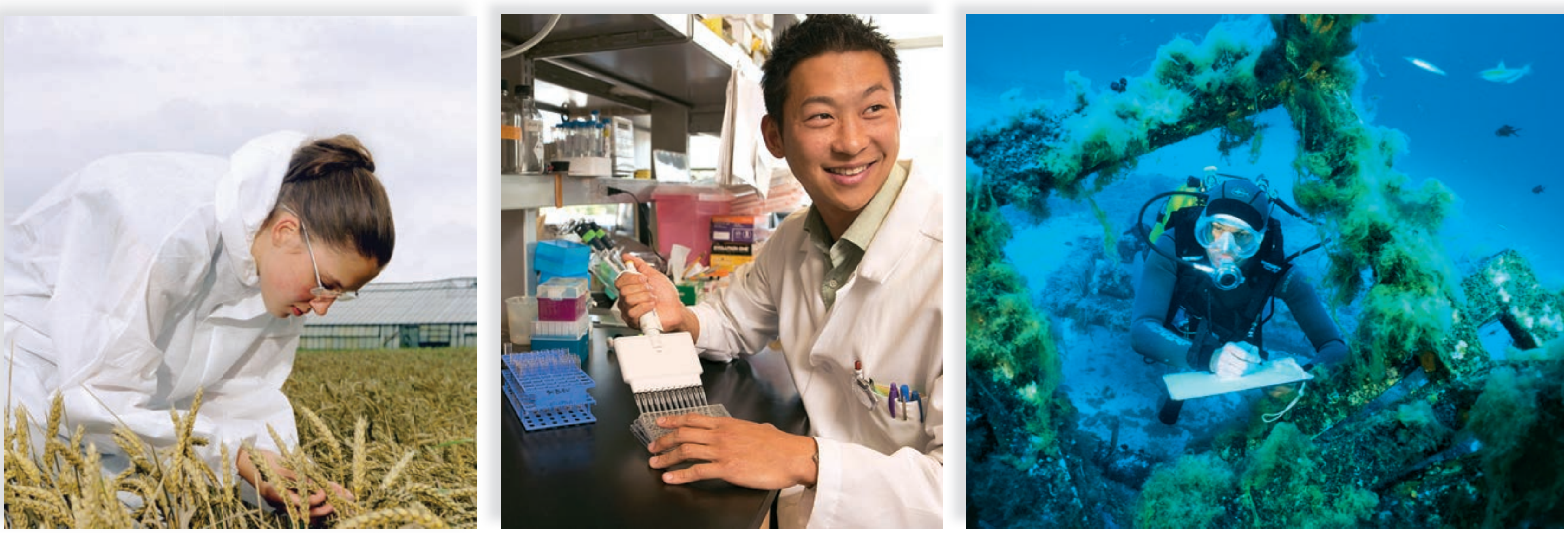
Despite the wide diversity of scientists and what they study (**Fig. 1.1A**), the usual four steps of the scientific method are: (1) making observations, (2) formulating a hypothesis, (3) performing experiments and making observations, and (4) coming to a conclusion (**Fig. 1.1B**).

Making Observations The scientific method begins with **observation.** We can observe with our noses that dinner is almost ready, observe with our fingertips that a surface is smooth and cold, and observe with our ears that a piano needs tuning. Scientists also extend the ability of their senses by using instruments; for example, the microscope enables them to see objects they could never see with the naked eye. Finally, scientists may expand their understanding even further by taking advantage of the knowledge and experiences of other scientists. For instance, they may look up past studies on the Internet or at the library, or they may write or speak to others who are researching similar topics.

Formulating a Hypothesis After making observations and gathering knowledge about a phenomenon, a scientist uses inductive reasoning. **Inductive reasoning** occurs whenever a person uses creative thinking to combine isolated facts into a cohesive whole. Chance alone can help a scientist arrive at an idea. The most famous case pertains to the antibiotic penicillin, which was discovered in 1928. While examining a petri dish of bacteria that had accidentally become contaminated with the mold *Penicillium,* Alexander Fleming observed an area around the mold that was free of bacteria. Fleming had long been interested in finding cures for human diseases caused by bacteria, and was very knowledgeable about antibacterial substances. So when he saw the dramatic effect of *Penicillium* mold on bacteria, he reasoned that the mold might be producing an antibacterial substance. We call such a possible explanation for a natural event a **hypothesis.** A hypothesis is based on existing knowledge, so it is much more informed than a mere guess. Fleming's hypothesis was supported by further observations. Sometimes a hypothesis is not supported, and must be either modified and subjected to additional study, or rejected.

All of a scientist's past experiences, no matter what they might be, may influence the formation of a hypothesis. But a scientist only considers hypotheses that can be tested by experiments or further observations. Moral and religious beliefs, while very important to our lives, differ between cultures and through time, and are not always testable.

FIGURE 1.1A Biologists work in a variety of settings.



Scientist in an agricultural field

Biochemist in a laboratory

Ecologist examining an artificial reef

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Performing Experiments and Making Observations Scientists often perform an **experiment,** a series of procedures to test a hypothesis. The manner in which a scientist intends to conduct an experiment is called its design. A good experimental design ensures that scientists are testing what they want to test and that their results will be meaningful. When an experiment is done in a laboratory, all conditions can be kept constant except for an **experimental variable,** which is deliberately changed. One or more **test groups** are exposed to the experimental variable, but one other group, called the **control group,** is not. If, by chance, the control group shows the same results as the test group, the experimenter knows the results are invalid.

Scientists often use a **model,** a representation of an actual object. For example, modeling occurs when scientists use software to decide how human activities will affect climate, or when they use mice instead of humans for, say, testing a new drug. Ideally, a medicine that is effective in mice should still be tested in humans. And whenever it is impossible to study the actual phenomenon, a model remains a hypothesis in need of testing. Someday, a scientist might devise a way to test it.

The results of an experiment or further observations are referred to as the **data.** Mathematical data are often displayed in the form of a graph or table. Sometimes studies rely on statistical data. Let's say an investigator wants to know if eating onions can prevent women from getting osteoporosis (weak bones). The scientist conducts a survey asking women about their onion-eating habits and then correlates these data with the condition of their bones. Other scientists critiquing this study would want to know: How many women were surveyed? How old were the women? What were their exercise habits? What criteria were used to determine the condition of their bones? And what is the probability that the data are in error? Even if the data do suggest a correlation, scientists would want to know if there is a specific ingredient in onions that has a direct biochemical or physiological effect on bones. After all, correlation does not necessarily mean causation. It could be that women who eat onions eat lots of vegetables, and have healthier diets overall than women who do not eat onions. In this way scientists are skeptics who always pressure one another to keep investigating.

Coming to a Conclusion Scientists must analyze the data in order to reach a **conclusion** about whether a hypothesis is supported or not. The data can support a hypothesis, but they do not prove it "true" because a conclusion is always subject to revision. On the other hand, it is possible to prove a hypothesis false. Because science progresses, the conclusion of one experiment can lead to the hypothesis for another experiment as represented by the return arrow in Figure 1.1B. In other words, results that do not support one hypothesis can often help a scientist formulate another hypothesis to be tested. Scientists report their findings in scientific journals so that their methodology and data are available to other scientists. Experiments and observations must be *repeatable*—that is, the reporting scientist and any scientist who repeats the experiment must get the same results, or else the data are suspect.

Scientific Theory The ultimate goal of science is to understand the natural world in terms of **scientific theories,** which are accepted explanations (concepts) for how the world works. The results of innumerable observations and experiments support a scientific theory. This text is organized around the following five basic theories of biology:

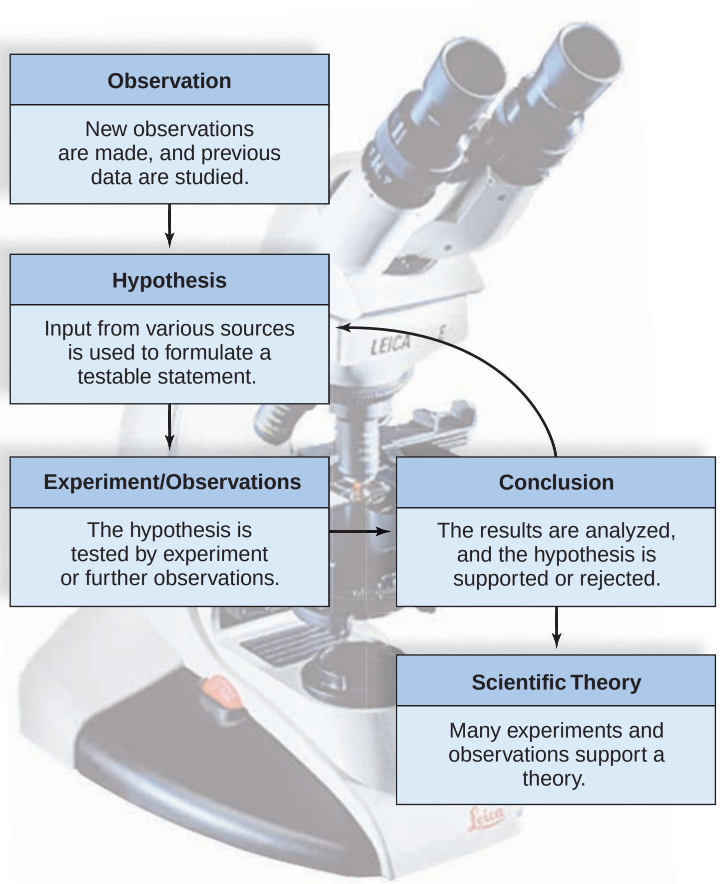

FIGURE 1.1B Flow diagram for the scientific method.

Theory	Concept
Cell	All organisms are composed of cells, and new cells only come from preexisting cells.
Gene	All organisms contain coded information that dictates their form, function, and behavior.
Evolution	All organisms have a common ancestor, but each is adapted to a particular way of life.
Homeostasis	All organisms have an internal environment that must stay relatively constant within a range protective of life.
Ecosystem	All organisms are members of populations that interact with each other and with the physical environment within a particular locale.

We will discuss these theories in detail later in the chapter, but right now let's turn our attention to an example of a scientific experiment.

1.1 Check Your Progress **You hypothesize that only the queen fire ant produces eggs. What type of data would allow you to come to a conclusion? What data would prove it false?**

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1.2 Control groups allow scientists to compare experimental results

Now that you are familiar with the common steps in the scientific method, let's consider an actual study that utilizes these steps. Because the use of synthetic nitrogen fertilizer is harmful to the environment (as described in "Organic Farming" on this page), researchers decided to study the yield of winter wheat utilizing a winter wheat/pigeon pea rotation. The pigeon pea is a **legume,** a plant that has root nodules where bacteria convert atmospheric nitrogen to a form plants such as winter wheat can use. The scientists formulated this hypothesis:

> **Hypothesis** A winter wheat/pigeon pea rotation will cause winter wheat production to increase as well as or better than the application of synthetic nitrogen fertilizer.

This study had a good design because it included test groups and a control group. Having a control group allows researchers to compare the results of the test groups. All environmental conditions for all groups is kept constant, but the test groups are exposed to an experimental variable, the factor being tested. The use of a control group also ensures that the data from the test groups are due to the experimental variable and not to some unknown outside influence. Test groups should be as large as possible to eliminate the influence of undetected differences in the test subjects.

The investigators decided to grow the winter wheat in pots and to have three sets of pots:

> **Control Pots** Winter wheat was planted in clay pots of soil that received no fertilization treatment—that is, no nitrogen fertilizer and no preplanting of pigeon peas.

> **Test Pots I** Winter wheat was grown in clay pots in soil treated with synthetic nitrogen fertilizer.

> **Test Pots II** Winter wheat was grown in clay pots following pigeon pea plants grown in the summertime. The pigeon pea plants were then turned over in the soil.

Results **Figure 1.2** includes a color-coded bar graph that allows you to see at a glance the comparative amount of wheat obtained from each group of pots. After the first year, winter wheat yield was higher in test pots treated with nitrogen fertilizer than in the control pots. To the surprise of investigators, test

HOW BIOLOGY IMPACTS OUR LIVES *Application*

1A Organic Farming

Besides being health conscious, people who buy organic may also be socially conscious. Organic farming is part of a movement to make agriculture sustainable by using farming methods that protect the health of people and ecosystems and preserve the land so that it can be productive for our generation and all future generations.

Modern agricultural methods have been dramatically successful at increasing yield, but at what price? We now know that modern farming practices lead to topsoil depletion and groundwater contamination. Without topsoil, the nutrient-rich layer that nourishes plants, agriculture is impossible, and yet modern farming practices such as tilling the land and allowing it to lie fallow (bare) allow topsoil to erode and disappear. One solution is to use a legume as a ground cover because it both protects and nourishes the soil (**Fig. 1A**). The researchers who did the study described in Section 1.2 used pigeon peas as a way to enrich the soil between winter wheat plantings.

Instead of growing legumes, farmers in recent years are accustomed to making plants bountiful by applying more and more synthetic nitrogen fertilizer. Unfortunately, nitrogen fertilizers pollute wells used for drinking water and also huge bodies of water, such as the Chesapeake Bay, the Gulf of Mexico, and the Great Lakes. Nitrates in the drinking water of infants leads to the "blue-baby" syndrome and possible death due to lack of oxygen in the blood. In adults, nitrates are implicated in causing digestive tract cancers. Certainly they can cause an algal bloom, recognized as a green scum on the water's surface.

In response to these problems, organic farmers severely limit the use of nitrogen fertilizers and instead rely on crop rotation, alternately planting a nitrogen-providing legume and a nitrogen-requiring crop such as wheat. Organic farmers also cut way back on the use of herbicides and pesticides, and this may be the primary reason you and others buy organic. The long-term consumption of these chemicals has been associated with such health problems as birth defects, nerve damage, and cancer. Children may be especially sensitive to health risks posed by pesticides; this is the chief reason lawns sprayed with pesticides carry warning signs. We should all be aware that we too can contribute to an organic lifestyle by limiting the use of synthetic chemicals on our lawns and gardens. In doing so, we improve our health and help preserve the environment for ourselves and future generations.

FIGURE 1A Legume plants have nodules.

FORM YOUR OPINION

1. The United States exports its current farming technology, with all its long-range problems, to other countries. Should this be continued?
2. What circumstances might discourage a farmer from growing food organically, and how might these obstacles be overcome?

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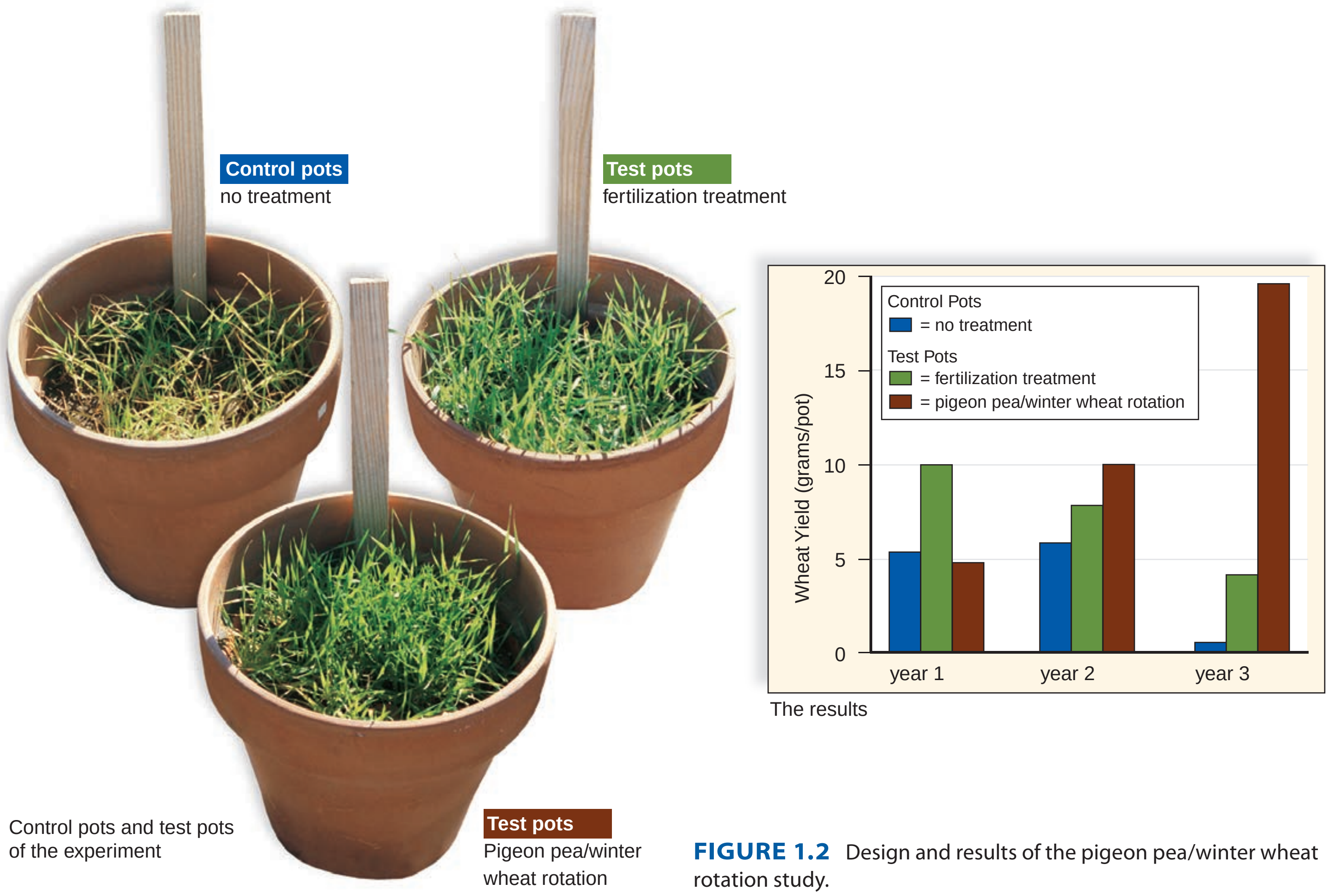

FIGURE 1.2 Design and results of the pigeon pea/winter wheat rotation study.

pots preplanted with pigeon peas did not produce as high a yield as the control pots.

> **Conclusion** The hypothesis was not supported. Wheat yield following the growth of pigeon peas was not as great as that obtained with nitrogen fertilizer treatments.

Follow-Up Experiment and Results The researchers decided to continue the experiment, using the same design and the same pots as before, to see whether the buildup of residual soil nitrogen from pigeon peas would eventually increase wheat yield to a greater extent than the use of nitrogen fertilizer. This was their new hypothesis:

> **Hypothesis** A sustained pigeon pea/winter wheat rotation will eventually cause an increase in winter wheat production.

They predicted that wheat yield following three years of pigeon pea/winter wheat rotation would surpass wheat yield following nitrogen fertilizer treatment.

Analysis of Results After two years, the yield from pots treated with nitrogen fertilizer was less than it had been the first year. Indeed, wheat yield in pots following a summer planting of pigeon peas was the highest of all the treatments. After three years, wheat yield in pots treated with nitrogen fertilizer was greater than in the control pots but not nearly as great as the yield in pots following summer planting of pigeon peas. Compared to the first year, wheat yield increased almost fourfold in pots having a pigeon pea/winter wheat rotation.

> **Conclusion** The hypothesis was supported. At the end of three years, the yield of winter wheat following a pigeon pea/winter wheat rotation was much better than for the other types of test pots.

To explain their results, the researchers suggested that the soil was improved by the buildup of the organic matter in the pots as well as by the addition of nitrogen from the pigeon peas. They published their results in a scientific journal,[1] where their experimental method and results would be available to the scientific community.

1.2 Check Your Progress **What would your control group and test groups be composed of if you were testing whether a parasite could reduce the size of a fire ant colony?**

[1]Bidlack, J. E., Rao, S. C., and Demezas, D. H. 2001. Nodulation, nitrogenase activity, and dry weight of chickpea and pigeon pea cultivars using different *Bradyrhizobium* strains. *Journal of Plant Nutrition* 24:549–60.

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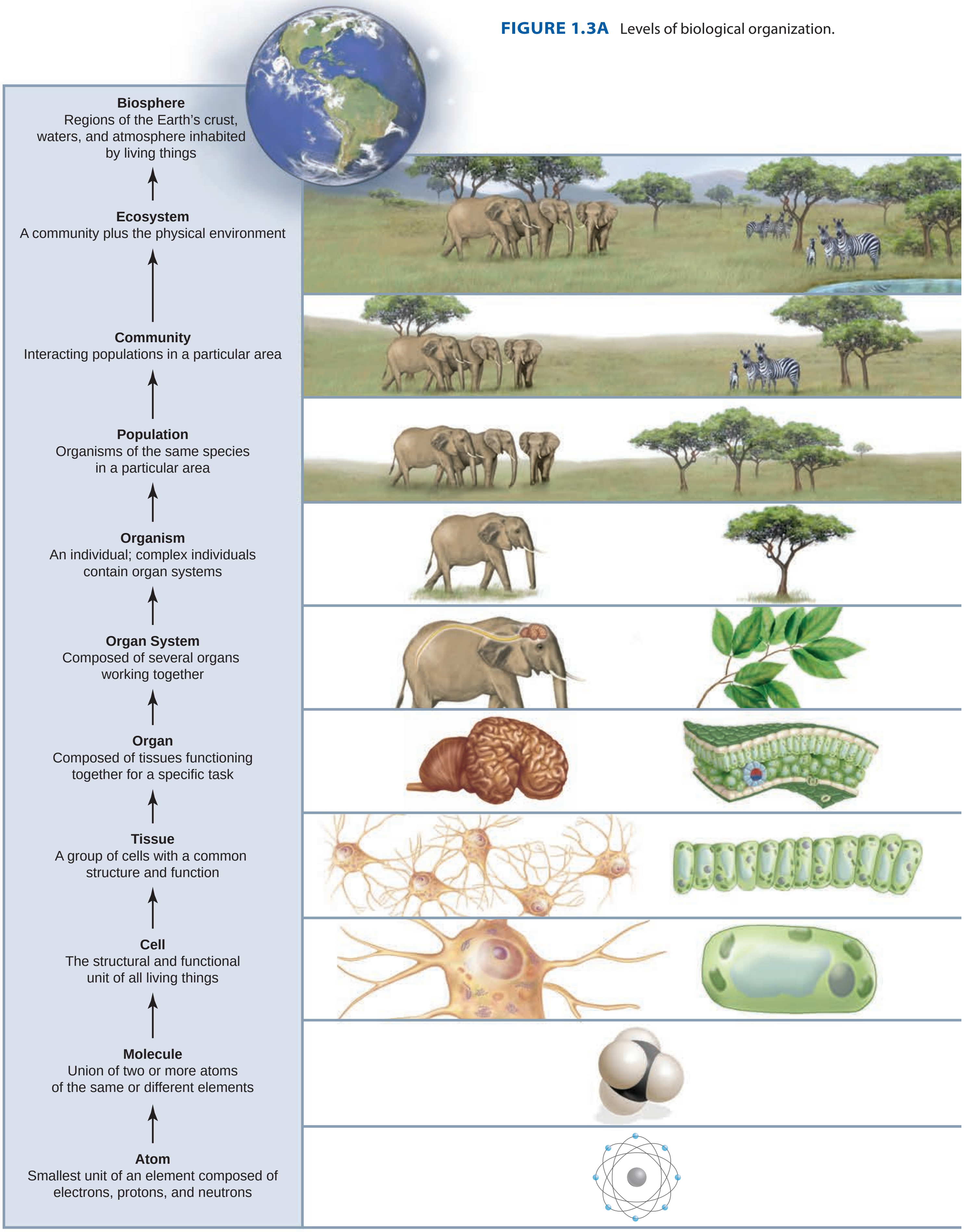
FIGURE 1.3A Levels of biological organization.



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THE CELL THEORY

Organisms Are Composed of Cells

Learning Outcomes

- Explain the unique place of cells in biological organization. (1.3)
- Relate the reproduction of cells and organisms and also their need for materials and energy to the cell theory. (1.3)

From huge menacing sharks to miniscule exotic orchids, life is very diverse. Despite this diversity, biologists have concluded that life can be understood in terms of the five theories that are emphasized in this text. The first theory we will discuss is the cell theory.

1.3 Cells are the fundamental unit of living things

Figure 1.3A illustrates very well why we will first discuss the **cell theory** which says that ***cells*** *are the fundamental unit of living things.* In a cell, **atoms,** the smallest portions of an element, combine with themselves or other atoms to form **molecules.** Although cells are composed of molecules, cells, and not molecules, are alive. Some cells, such as unicellular paramecia, live independently. Other cells, such as those of the alga *Volvox,* cluster together in microscopic colonies. An elephant is a multicellular organism in which similar cells combine to form a **tissue;** one common tissue in animals is nerve tissue. Tissues make up **organs,** as when various tissues combine to form the brain. Organs work together in **organ systems;** for example, the brain works with the spinal cord and a network of nerves to form the nervous system. Organ systems are joined together to form a complete living thing, or **organism.** Only a microscope can reveal that organisms are composed of cells (**Fig. 1.3B**).

Later in this chapter, we will consider the higher levels of biological organization shown in Figure 1.3A.

Cells Come from Other Cells Cells come only from a previous cell, and organisms come only from other organisms. In other words, cells and organisms **reproduce.** Every type of living thing can reproduce, or make another organism like itself. Bacteria, protists, and other unicellular organisms simply split in two. In most multicellular organisms, the reproductive process is more complex. It begins with the pairing of a two cells—a sperm from one partner and an egg from the other partner. The union of sperm and egg, followed by many cell divisions, results in an immature stage that grows and develops through various stages to become an adult.

Cells Use Materials and Energy Cells and organisms cannot maintain their organization or carry on life's activities without an outside source of nutrients and energy. Nutrients function as building blocks or for energy. **Energy** is the capacity to do work, and it takes work to maintain the organization of the cell and the organism. When cells use nutrients to make their parts and products, they carry out a sequence of chemical reactions. Nerve cells and muscle cells also use energy as organisms move about. The term **metabolism** encompasses all the chemical reactions that occur in a cell.

The ultimate source of energy for nearly all life on Earth is the sun. Plants and certain other organisms are able to capture solar energy and carry on **photosynthesis,** a process that transforms solar energy into the chemical energy of organic nutrients. All life on Earth acquires energy by metabolizing nutrients made by photosynthesizers. This applies even to plants.

1.3 Check Your Progress Explain (a) how life has order, (b) how it reproduces, and (c) how it acquires energy.

a. b. c.

FIGURE 1.3B Only micrographs (pictures taken microscopically), such as the one in **(c)**, can reveal that organisms are composed of cells.

THE GENE THEORY

Genes Control the Traits of Organisms

Learning Outcomes

- Relate the gene theory to the diversity of life. (1.4)
- Describe several applications of the gene theory. (1.4)

The cell theory studied in Section 1.3 and the gene theory are intimately connected. Genes are housed in cells, and when cells divide, they pass on genes to the next cell or organism. Genes code for proteins, and it is proteins that directly bring about the traits of organisms.

1.4 Organisms have a genetic inheritance

A nineteenth-century scientist named Gregor Mendel is often called the father of genetics because he was the first to conclude, following experimentation with pea plants, that units of heredity now called **genes** are passed from parents to offspring. Later investigators, notably James Watson and Francis Crick, discovered that genes are composed of the molecule known as **DNA** (deoxyribonucleic acid). The work of these and many other investigators allows us to state the first premise of the **gene theory:** *Genes are hereditary units composed of DNA*. Our increasing knowledge of DNA tells us that genes contain coded information that controls the structure and function of cells and organisms. The spiral staircase structure of DNA contains four different types of molecules called nucleotides, each represented by a different color (**Fig. 1.4**). DNA can **mutate** (undergo permanent changes), and each type of organism, such as those depicted in Figure 1.4, has its own particular sequence of these four nucleotides. This is called coded information because a particular nucleotide sequence codes for a particular protein. **Proteins** are cellular molecules that determine what the cell and the organism are like. The second premise of the gene theory is: *Genes control the structure and function of cells and organisms* by coding for proteins.

The gene theory has been extremely fruitful, meaning that it has led to much experimentation and many applications. Every field of biology and most aspects of our lives have changed because of the ability to analyze and manipulate DNA. Here are a few examples:

Basic Genetic Research

We can extract DNA and study metabolism at the molecular level. Therefore, we will soon know how one cell type differs from another.

We can also sequence the nucleotides in DNA and study how the metabolism of DNA is regulated. One day we will know how this makes humans different from chimpanzees, for example.

Relationship of Species

DNA technology aids in discovering the history of life on Earth—that is, who is related to whom. For example, a recent comparative study concluded that early humans did not interbreed with the archaic humans known as Neandertals.

Wildlife biologists use DNA sequence data to determine how best to conserve various species.

Medicine

Genetic testing can tell us what diseases we are prone to, and doctors can use this information to prescribe drug therapy or tell us how best to protect ourselves.

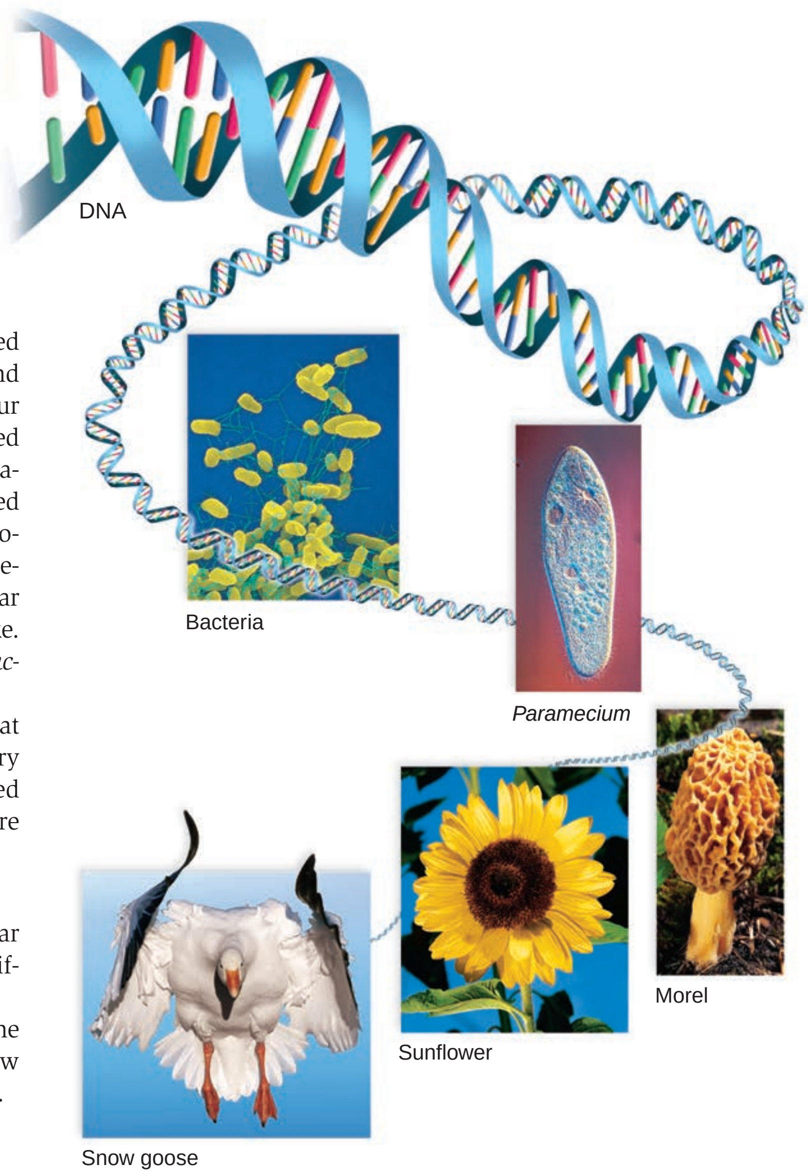

FIGURE 1.4 DNA differences account for the variety of life on Earth as exemplified by these examples.

Drugs for diabetes, blood disorders, vaccines, and many other diseases are now made by utilizing DNA technology.

1.4 Check Your Progress Explain how genetic inheritance is a part of reproduction.

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THE THEORY OF HOMEOSTASIS

Organisms Are Homeostatic

Learning Outcomes

- State and explain the concept of homeostasis. (1.5)
- Describe how an organism's ability to respond to stimuli relates to homeostasis. (1.5)

To survive, cells and organisms must maintain a state of biological balance, or **homeostasis.** For example, temperature, moisture level, acidity, and other physiological factors must remain within the tolerance range of cells.

1.5 Organisms regulate their internal environment

The **theory of homeostasis** tells us that *cells and organisms have an internal environment* and that *cells regulate this environment so that it stays fairly constant*. While individual cells are homeostatic, most examples of homeostasis involve multicellular organisms. Animals have intricate feedback and control mechanisms that do not require any conscious activity. For example, when a student is so engrossed in her textbook that she forgets to eat lunch, her liver releases stored sugar to keep her blood sugar level within normal limits. In this case, hormones regulate sugar storage and release, but in other instances, the nervous system is involved in maintaining homeostasis.

Many animals depend on behavior to regulate their internal environment. The same student may realize that she is hungry and decide to visit the local diner. Iguanas may raise their internal temperature by basking in the sun (**Fig. 1.5A**) or cool down by moving into the shade. Similarly, fire ants move upward into the mound when the warmth of the sun is needed and move back down into their cooler subterranean passageways when the sun is too hot.

We will see that plants are, to a degree, homeostatic. For example, they bend toward sunlight and have mechanisms that contain the damage done by hungry insects to their leaves or infections caused by bacteria and viruses.

FIGURE 1.5B Plants respond to light by bending toward it.

FIGURE 1.5A Iguanas bask in the sun to raise their body temperature.

Response to Stimuli The ability to respond to stimuli assists the homeostatic ability of organisms. For example, only because they can repond to the presence of predaceous insects can plants protect their integrity. Even unicellular organisms can respond to their environment. For some, the beating of microscopic hairs, and for others, the snapping of whiplike tails move them toward or away from light or chemicals. Multicellular organisms can manage more complex responses. A vulture can detect a carcass a mile away and soar toward dinner. A monarch butterfly can sense the approach of fall and begin its flight south where resources are still abundant.

When a plant bends toward a source of light (**Fig. 1.5B**), it acquires the energy it needs for photosynthesis, and when an animal darts safely away from danger, it lives another day. All together, daily activities are termed the behavior of the organism. Organisms display a variety of behaviors as they search and compete for energy, nutrients, shelter, and mates. Many organisms display complex communication, hunting, and defensive behaviors as well. The behavior of an organism often assists homeostasis.

1.5 Check Your Progress **Explain the relationship between homeostasis and response to a stimulus.**

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THE THEORY OF ECOSYSTEMS

Organisms Live in Ecosystems

Learning Outcomes

- Describe the various levels of biological organization beyond the organism. (1.6)
- Describe how an ecosystem functions. (1.6)

The organization of life extends beyond the individual to the **biosphere,** the zone of air, land, and water at the Earth's surface where living organisms are found. Individual organisms belong to a **population,** all the members of a species within a particular area. The populations within a **community** interact among themselves and with the physical environment (soil, atmosphere, etc.), thereby forming an **ecosystem.**

1.6 The biosphere is divided into ecosystems

The **theory of ecosystems** says that *organisms form units in which they interact with the biotic (living) and abiotic (nonliving) components of the environment.* One example of an ecosystem is a North American grassland, which is inhabited by populations of rabbits, hawks, and many other animals, as well as various types of grasses. These populations interact by forming food chains in which one population feeds on another. For example, rabbits feed on grasses, while hawks feed on rabbits and other organisms.

As **Figure 1.6** shows, ecosystems are characterized by *chemical cycling* and *energy flow,* both of which begin when plants, such as grasses, take in solar energy and inorganic nutrients to produce food (organic nutrients) by photosynthesis. Chemical cycling (gray arrows) occurs as chemicals move from one population to another in a food chain, until death and decomposition allow inorganic nutrients to be returned to the photosynthesizers once again. Energy (red arrows), on the other hand, flows from the sun through plants and the other members of the food chain as they feed on one another. The energy gradually dissipates and returns to the atmosphere as heat. Because energy does not cycle, ecosystems could not stay in existence without solar energy and the ability of photosynthesizers to absorb it.

The Biosphere Climate largely determines where different ecosystems are found in the biosphere. For example, deserts exist in areas of minimal rain, while forests require much rain. The two most biologically diverse ecosystems—tropical rain forests and coral reefs—occur where solar energy is most abundant. The human population tends to modify these and all ecosystems for its own purposes. Humans clear forests or grasslands in order to grow crops; later, they build houses on what was once farmland; and finally, they convert small towns into cities. As coasts are developed, humans send sediments, sewage, and other pollutants into the sea.

Tropical rain forests and coral reefs are home to many organisms. The canopy of the tropical rain forest alone supports a variety of organisms, including orchids, insects, and monkeys. Coral reefs, which are found just offshore in the Southern Hemisphere, provide a habitat for many animals, including jellyfish, sponges, snails, crabs, lobsters, sea turtles, moray eels, and some of the world's most colorful fishes. Like tropical rain forests, coral reefs are severely threatened as the human population increases in size. Aside from pollutants, overfishing and collection of coral for sale to tourists destroy the reefs.

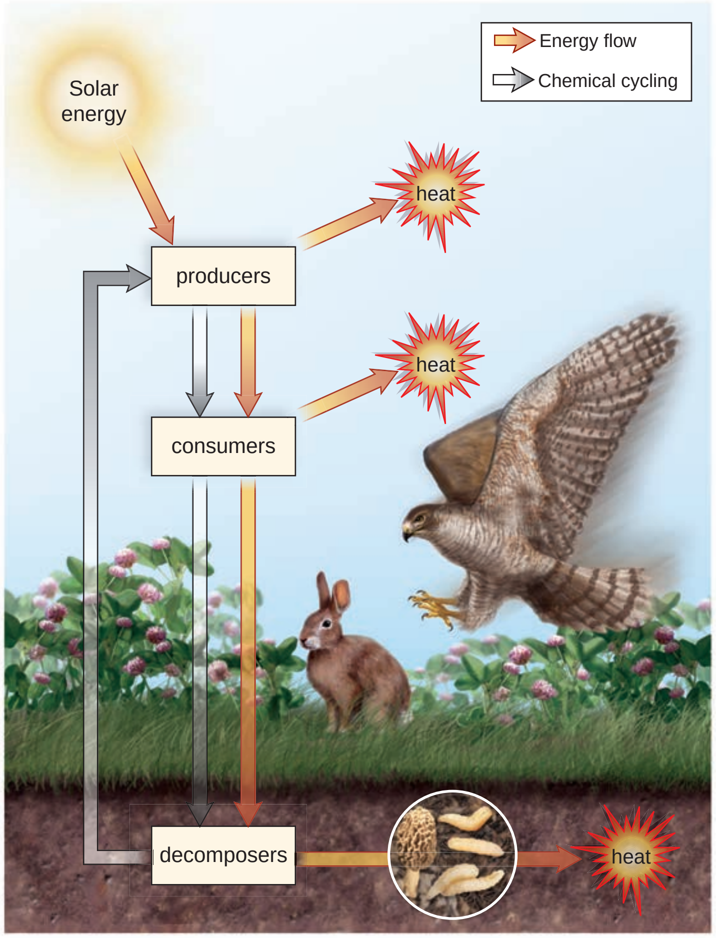

FIGURE 1.6 A grassland is a major ecosystem. Chemicals cycle because decomposers return inorganic nutrients to producers which provide organic nutrients to consumers including decomposers. With each transfer of nutrients, energy is lost as heat.

It has long been clear that human beings depend on healthy ecosystems for food, medicines, and various raw materials. We are only now beginning to realize that we depend on them even more for the services they provide. The workings of ecosystems ensure that environmental conditions are suitable for the continued existence of humans.

1.6 Check Your Progress Give a specific example to illustrate that we depend on natural ecosystems.

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THE THEORY OF EVOLUTION

Organisms Are Related and Adapted to Their Environment

Learning Outcomes

- Use a simple evolutionary tree to show how organisms are related. (1.7)
- List the major categories of classification, and explain how data are used to classify organisms. (1.8)
- Describe adaptation to the environment by the process of natural selection. (1.9)
- State seven characteristics that define life. (1.10)

Evolution explains the unity and diversity of life. All organisms share the same characteristics because they are descended from a common source. During descent, however, life changes as different forms become adapted to their environment. Evolution is the unifying concept of biology because it can explain so many aspects of life, including why organisms have shared characteristics despite their great diversity.

1.7 The ancestry of species can be determined

The **theory of evolution** says that *organisms have shared characteristics because of common descent.* Just as you and your close relatives can trace your ancestry to a particular pair of great grandparents, so species can trace their ancestry to a common source. An **evolutionary tree** is like a family tree. Just as a family tree shows how a group of people have descended from one couple, an evolutionary tree traces the ancestry of a group to a **common ancestor.** In the same way that one couple can have diverse children, a population can be a common ancestor to several other groups. Over time, diverse life-forms have arisen.

Biologists have discovered that it is possible to trace the evolution of any group—and even life itself—by using molecular data, the fossil record, the anatomy and physiology of organisms, and the embryonic development of organisms. The common ancestors for birds are known from the fossil record, and *Archaeopteryx,* an early bird, clearly has reptile characteristics (**Fig. 1.7A**). Because the evidence is so clear, birds are now classified as reptiles. Some biologists call them flying dinosaurs. The reptiles that exist today include crocodiles, lizards, snakes, and turtles and birds! The evolutionary tree in **Figure 1.7B** traces the ancestry of *Archaeopteryx* to an early reptilian ancestor.

In Section 1.8 we will examine an evolutionary tree of life and consider how organisms are classified. Then in Section 1.9 we will show that natural selection is the mechanism that results in adaptation to the environment, such as the ability of birds to fly. One important thing to remember is that only species (types of organisms) evolve and not individual organisms. Genetics can help you understand why. The genetic makeup you inherited from your parents can mutate during your lifetime and cause cellular changes, but this does not cause your basic characteristics to change. On the other hand, mutations that show up in populations can be selected for increased representation in the next generation.

1.7 Check Your Progress **Humans are not descended from apes; they share a common ancestor with apes. Explain the difference.**

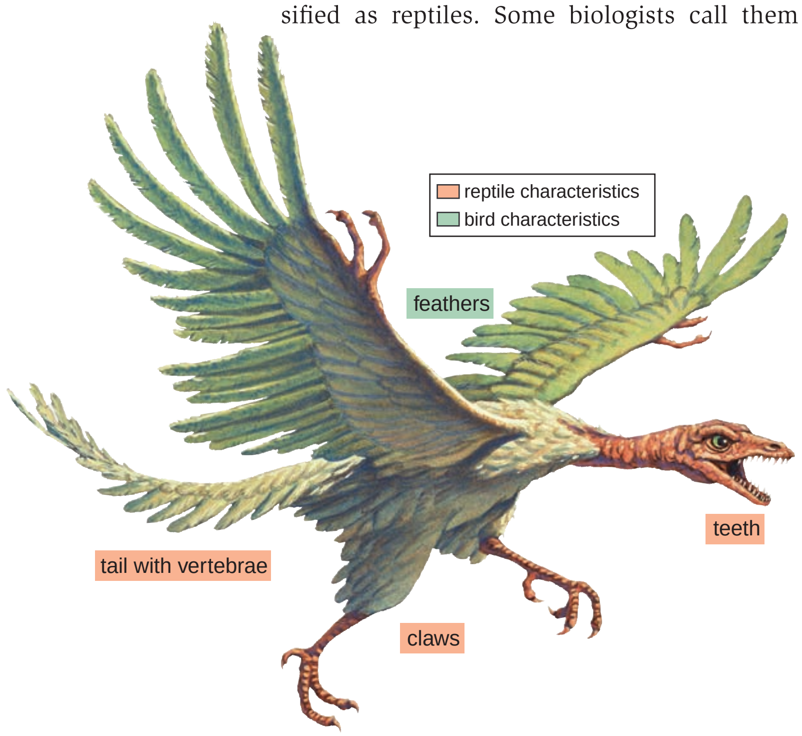

FIGURE 1.7A This depiction of *Archaeopteryx* shows its bird and reptile characteristics.

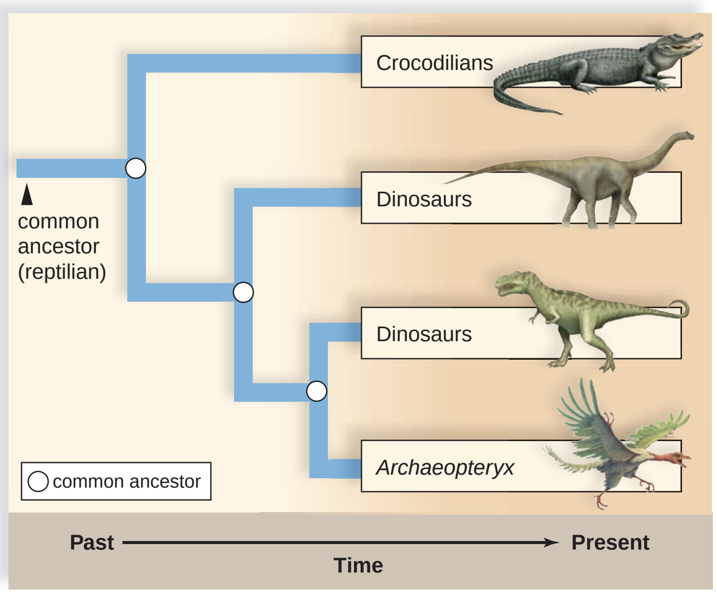

FIGURE 1.7B An evolutionary tree shows how the ancestry of *Archaeopteryx* can be traced to a common ancestor with crocodiles and dinosaurs. Each circle is an intervening common ancestor.

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1.8 Evolutionary relationships help biologists group organisms

Despite their diversity, organisms share certain characteristics, and this can be explained by evolution from a common source. For example, all forms of life are composed of cells and use DNA as their genetic material. **Figure 1.8A** is an evolutionary tree that shows how major groups of organisms are related through evolution.

Organizing Diversity Because life is so diverse, it is helpful to group organisms into categories. **Taxonomy** is the discipline of identifying and grouping organisms according to certain rules. Taxonomy makes sense out of the bewildering variety of life on Earth and is meant to provide valuable insight into evolution. As more is learned about living things, including the evolutionary relationships between species, taxonomy changes. DNA technology is now being used to revise current information and to discover previously unknown relationships between organisms.

The basic classification categories, or taxa, going from least inclusive to most inclusive, are **species, genus, family, order, class, phylum, kingdom,** and **domain** (**Table 1.8**). The least inclusive category, species, is defined as a group of interbreeding individuals. Each successive classification category above species contains more types of organisms than the preceding one. Species placed within one genus share many specific characteristics and are the most closely related, while species placed in the same kingdom share only general characteristics with one another. For example, all species in the genus *Pisum* look pretty much the same—that is, like pea plants—but species in the plant kingdom can be quite varied, as is evident when we compare grasses to trees. Species placed in different domains are the most distantly related.

Domains Biochemical evidence suggests that there are only three domains: **Bacteria, Archaea,** and **Eukarya.** Figure 1.8A shows how the domains are related. Both domain Bacteria and domain Archaea evolved from the first common ancestor soon after life began. These two domains contain the unicellular **prokaryotes,** which lack the membrane-bounded nucleus found in the **eukaryotes** of domain Eukarya. However, the DNA of archaea differs from that of bacteria, and their cell surface is chemically more similar to eukaryotes than to bacteria. So, biologists have concluded that eukarya split off from the archaeal line of descent. Prokaryotes are structurally simple but metabolically complex. Archaea (**Fig. 1.8B**) can live in aquatic environments that lack oxygen or are too salty, too hot, or too acidic for most other organisms. Perhaps these environments are similar to those of the primitive Earth, and archaea are the least evolved forms of life, as their name implies. Bacteria (**Fig.1.8C**) are variously adapted to living almost anywhere—in water, soil, and the atmosphere, as well as on our skin and in our mouths and large intestines.

TABLE 1.8 Levels of Classification

	Human	Corn
Domain	Eukarya	Eukarya
Kingdom	Animalia	Plantae
Phylum	Chordata	Anthophyta
Class	Mammalia	Monocotyledones
Order	Primates	Commelinales
Family	Hominidae	Poaceae
Genus	*Homo*	*Zea*
Species*	*H. sapiens*	*Z. mays*

*To specify an organism, you must use the full binomial name, such as *Homo sapiens.*

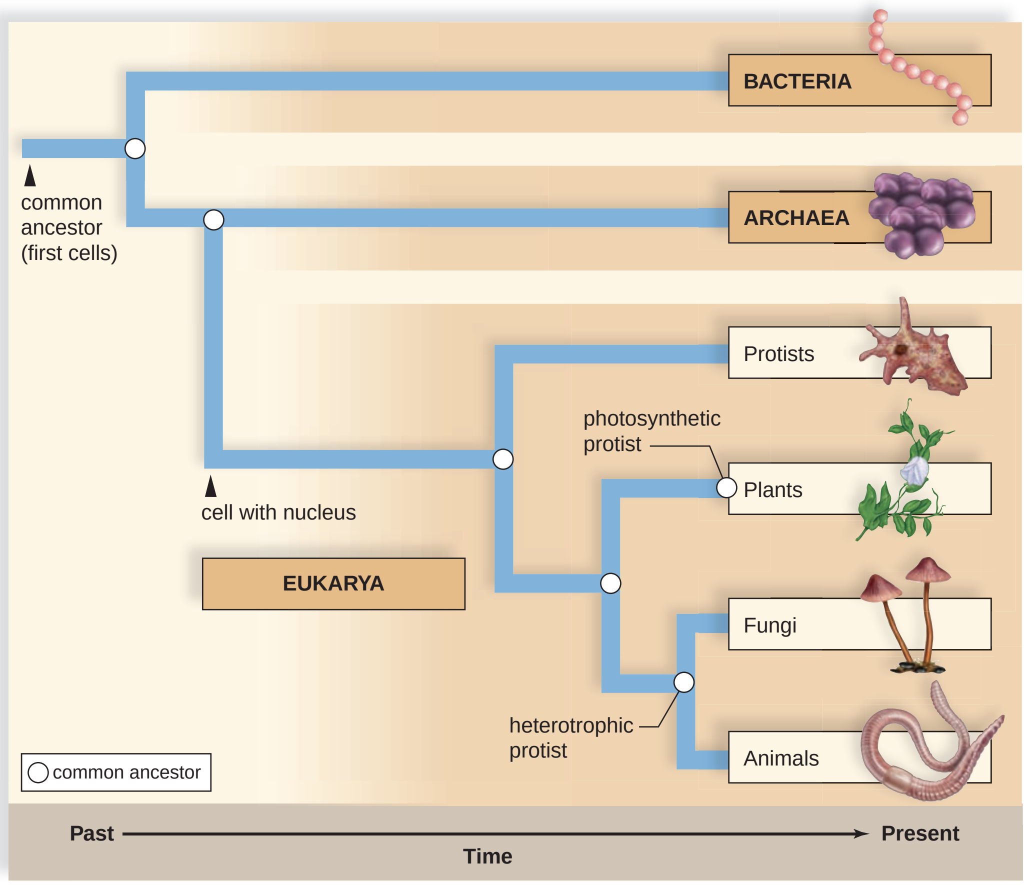

FIGURE 1.8A All species have a common ancestor that existed about four billion years ago. Domains Bacteria and Archaea were the first to appear. Domain Eukarya, which includes protists, plants, fungi, and animals, shares an ancestor with domain Archaea.

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Taxonomists are in the process of deciding how to categorize the organisms within domains Archaea and Bacteria into kingdoms. Domain Eukarya, on the other hand, contains four major groups of organisms (**Fig. 1.8D**). **Protists,** which now comprise a number of kingdoms, range from unicellular forms to a few multicellular ones. Some are photosynthesizers, while others must acquire their food. Common protists include algae, the protozoans, and the water molds. Figure 1.8A shows that plants, fungi, and animals evolved from protists. **Plants** (kingdom Plantae) are multicellular photosynthetic organisms. Examples of plants include azaleas, zinnias, and pines. Among the **fungi** (kingdom Fungi) are the familiar molds and mushrooms that, along with bacteria, help decompose dead organisms. **Animals** (kingdom Animalia) are multicellular organisms that must ingest and process their food. Aardvarks, jellyfish, and zebras are representative animals.

Scientific Names Biologists use binomial nomenclature to assign each living thing a two-part name called its scientific name. For example, the scientific name for mistletoe is *Phoradendron tomentosum*. The first word is the genus, and the second word is the **specific epithet** of a species within that genus. The genus may be abbreviated (e.g., *P. tomentosum*), and if the species is unknown it may be indicated by sp. (e.g., *Phoradendron* sp.). Scientific names are universally used by biologists to avoid confusion. Common names tend to overlap and are often in the language of a particular country. Scientific names are based on Latin, a universal language that not too long ago was well known by most scholars.

1.8 Check Your Progress **a. Fire ants belong to what domain and what kingdom? b. What types of data did biologists use to draw the tree of life depicted in Figure 1.8A?**

- Prokaryotic cells of various shapes
- Adaptations to extreme environments
- Absorb or chemosynthesize food
- Unique chemical characteristics

Methanosarcina mazei, an archaeon 1.6 µm

FIGURE 1.8B Domain Archaea.

- Prokaryotic cells of various shapes
- Adaptations to all environments
- Absorb, photosynthesize, or chemosynthesize food
- Unique chemical characteristics

Escherichia coli, a bacterium 1.5 µm

FIGURE 1.8C Domain Bacteria.

Protists

- Algae, protozoans, slime molds, and water molds
- Complex single cell (sometimes filaments, colonies, or even multicellular)
- Absorb, photosynthesize, or ingest food

Paramecium, a unicellular protozoan

KINGDOM: Plants

- Certain algae, mosses, ferns, conifers, and flowering plants
- Multicellular, usually with specialized tissues, containing complex cells
- Photosynthesize food

Passiflora, passion flower, a flowering plant

KINGDOM: Fungi

- Molds, mushrooms, yeasts, and ringworms
- Mostly multicellular filaments with specialized, complex cells
- Absorb food

Coprinus, a shaggy mane mushroom

KINGDOM: Animals

- Sponges, worms, insects, fishes, frogs, turtles, birds, and mammals
- Multicellular with specialized tissues containing complex cells
- Ingest food

Vulpes, a red fox

FIGURE 1.8D Domain Eukarya.

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1.9 Evolution through natural selection results in adaptation to the environment

The phrase "common descent with modification" sums up the process of evolution because it means that, as descent occurs from common ancestors, modifications occur that cause these organisms to be adapted (suited) to the environment. Through many observations and experiments, Charles Darwin, the father of evolution, came to the conclusion that natural selection is the process that makes modification—that is, **adaptation**—possible. In other words, the theory of evolution also states that, as evolution occurs, ***natural selection*** *brings about adaptation to the environment.* Adaptation to various environments accounts for the diversity of life.

Natural Selection During the process of natural selection, some aspect of the environment selects which traits are more apt to be passed on to the next generation. The selective agent can be an abiotic agent (part of the physical environment, such as altitude) or a biotic agent (part of the living environment, such as a deer). **Figure 1.9A** shows how deer could act as a selective agent for a particular mutant. Mutations fuel natural selection because mutations introduce variations among the members of a population. In Figure 1.9A, a plant species generally produces smooth leaves, but a mutation occurs that causes one plant's leaves to be covered with small extensions or "hairs." The plant with hairy leaves has an advantage because the deer (the selective agent) prefer to eat smooth leaves rather than hairy leaves. Therefore, the plant with hairy leaves survives best and produces more seeds than most of its neighbors. As a result, generations later most plants of this species produce hairy leaves.

As with this example, Darwin realized that although all individuals within a population have the ability to reproduce, not all do so with the same success. Prevention of reproduction can run the gamut from an inability to capture resources, as when long-necked, but not short-necked, giraffes can reach their food source, to an inability to escape being eaten because long legs, but not short legs, can carry an animal to safety. Whatever the example, it can be seen that living things having advantageous traits can produce more offspring than those lacking them. In this way, living things change over time, and these changes are passed on from one generation to the next. Over long periods of time, the introduction of newer, more advantageous traits into a population causes a species to become adapted to an environment.

For example, rockhopper penguins (**Fig. 1.9B**) are adapted to an aquatic existence in the Antarctic. An extra layer of downy feathers is covered by short, thick feathers that form a waterproof coat. Layers of blubber also keep the birds warm in cold water. Most birds have forelimbs proportioned for flying, but penguins have stubby, flattened wings suitable for swimming. Their feet and tails serve as rudders in the water, but their flat feet also allow them to walk on land. Rockhopper penguins hop from one rock to another and have a bill adapted to eating small shellfish. Penguins also have many behavioral adaptations for living in the Antarctic. They often slide on their bellies across the snow in order to conserve energy when moving quickly. Their eggs—one, or at most two—are carried on the feet, where they are protected by a pouch of skin. This allows the birds to huddle together for warmth while standing erect and incubating eggs.

▶ **1.9 Check Your Progress** **Explain how natural selection results in the adaptations of a species.**

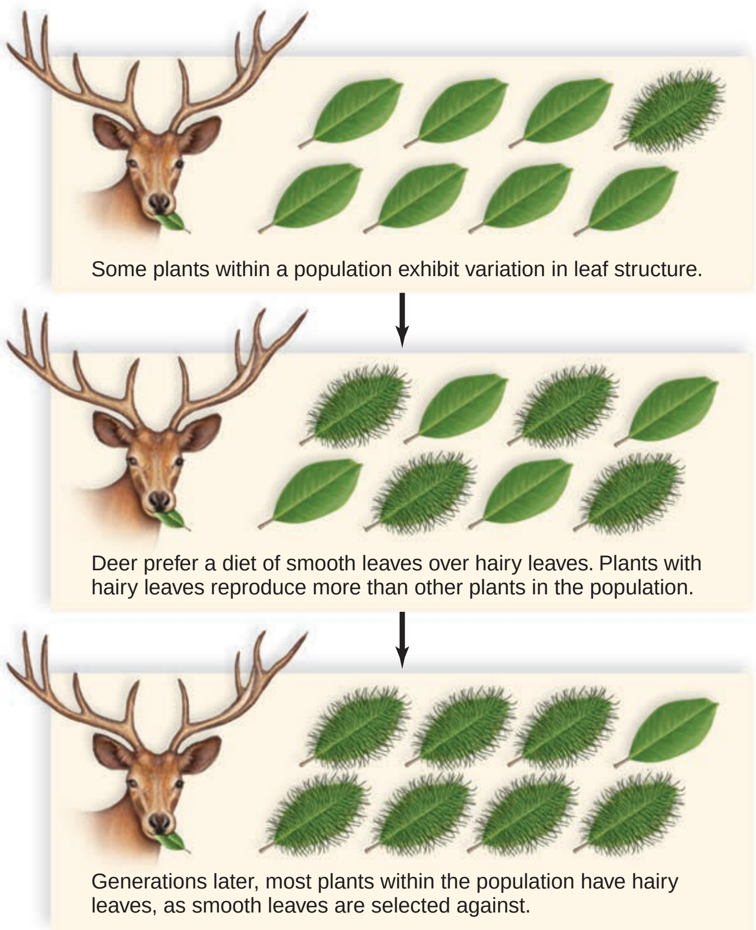

FIGURE 1.9A Predatory deer act as a selective agent to bring about change in a plant population.

FIGURE 1.9B Rockhopper penguins are adapted to swimming in the icy waters of Antarctica.

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HOW LIFE CHANGES **Application**

1B Evolution's Many Applications

The principles of evolution not only increase our understanding of how the world works but also help us solve practical problems that impact our lives. Many good examples can be cited in the fields of agriculture, medicine, and conservation.

Agriculture

The fruit of the wild banana plant is small and tough with large hard seeds. In contrast, the bananas we eat today are large, soft, sweet, and for practical purposes seedless. Humans produced this type of banana by using **artificial selection;** in this case, humans were the selective agent and not the environment. Most of the vegetables we eat today, and our domesticated animals including horses, dogs, and cows, were produced in the same way.

Understanding the evolution of our agricultural plants helps us keep them healthy. For example, maize chlorotic dwarf virus (MCDV) causes an infection of young corn plants that makes them sick and reduces yield. However, it's known that our domesticated corn is derived from wild plants called teosinte, and scientists have found teosinte species in the wild that are resistant to several viral diseases, including the one caused by MCDV. This gene has been transferred to corn plants so that they too are resistant.

Farmers use pesticides to protect their crops from insects, or they grow plants that have been engineered to produce the pesticide. However, the pesticide is a selective agent for those members of the insect population that carry genes for the resistant trait. Because these insects reproduce more than nonresistant insects, a large percentage of the insect population becomes resistant. Understanding this process has caused scientists to suggest that farmers make a part of their fields pesticide free. This will allow nonresistant insects to also reproduce, and in this way the percentage of resistant insects in the next generation will be reduced.

Medicine

In the presence of an antibiotic, resistant bacteria are selected to reproduce over and over again, until the entire population of bacteria becomes resistant to the antibiotic. In 1959, a new antibiotic called methicillin became available to treat bacterial infections that were already resistant to penicillin. By 1997, 40% of hospital staph infections were caused by MRSA (methicillin-resistant *Staphylococcus aureus*). By now, the same bacteria can spread freely through the general population when people are in close contact. The infection is called CA-MRSA (community-acquired MRSA).

A knowledge of evolution has not only allowed scientists to understand how pathogens (e.g., bacteria and viruses) become resistant to antibiotics, but has also helped them create a process to develop new drugs to kill them. Millions of possible drugs are selected based on their ability to kill a particular pathogen. Then the best of these are tweaked chemically before this new patch of chemicals are tested for their ability to kill the pathogen. This selection process is repeated time and time again until a new drug has been developed. This drug is then tested in another mammal (e.g., mouse) or another primate (e.g., chimpanzee) that is closely related to humans through evolution. If the drug has few harmful side effects, it is prescribed to humans to cure the disease.

Conservation

A knowledge of evolution helps scientists decide which technologies can help save the environment. For example, most of us still fill the tanks of our cars with gasoline derived from oil. Yet oil is a nonrenewable resource that will eventually be depleted. What we need is a renewable resource that can be replaced over and over again. Corn is a renewable resource that can be used to produce ethanol, a fuel that substitutes for gasoline and is somewhat better for the environment. Furthermore, some scientists believe that, instead of using corn, which is food for animals and humans, billions of tons of currently unused waste materials in the United States are available for ethanol production. By mocking the natural selection process as described above for perfecting a drug, the best bacteria for changing waste to ethanol could be arrived at. Using the natural selection process to achieve the best drug or the best bacterium or to select anything for a particular task is now described as using *directed evolution*.

A knowledge of evolution can also help us save endangered species in the wild. For example, some populations of chinook salmon are listed under the U.S. Endangered Species Act as either threatened or endangered. To save them, it is possible to build hatcheries, breed more fish, and introduce these fish into rivers where small populations of wild chinook salmon now live. However, this will not work if the captive fish have inadvertently undergone selection for reproduction in hatcheries but not in rivers. Therefore, hatcheries should mimic as much as possible the selection pressures that wild populations are exposed to. Only in that way can the introduced chinook salmon help save wild populations and our efforts will not have been wasted.

FORM YOUR OPINION

1. Give examples of how a knowledge of evolution can help humans solve practical problems that impact their lives.
2. Explain why it benefits farmers to set aside part of their fields where nonresistant insects can reproduce.
3. Give reasons why captive chinook salmon introduced into the wild need to have been exposed to the same environmental pressures as wild populations.

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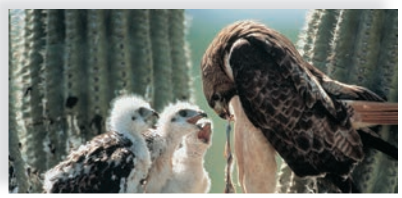
1.10 Evolution from a common ancestor accounts for the characteristics of life

The diversity of life has been mentioned several times by now. With so much diversity, how can we possibly define life? The best way we know to distinguish the living from the nonliving is to list the characteristics shared by all organisms. These characteristics of life must have been present in the original common ancestor or else they would not be present in all organisms.

1. **Life is organized.** The levels of biological organization extend from cells to the biosphere; see p. 8. The first living organisms were unicellular, and only later did multicellular forms arise. Once several different types of organisms arose, they interacted among themselves and became the biotic components of ecosystems.
2. **Life uses materials and energy.** The metabolic pathways that allow an organism to maintain its organization and to grow are the same in all organisms; see p. 9. We will study these metabolic pathways in future chapters because they are so critical to the lives of organisms.
3. **Life reproduces.** Unicellular organisms simply divide when they reproduce, but in multicellular forms, new life often begins with a fertilized egg that grows and develops into a new organism. When organisms reproduce, genetic differences arise that allow evolution to occur; see pp. 9–10.
4. **Life is homeostatic.** Regulatory mechanisms allow cells and organisms to keep their internal environment relatively constant; see p. 11. Homeostasis evolved because those members of a population that were homeostatic had more offspring than those that were less homeostatic.
5. **Life responds to stimuli.** Organisms respond to internal stimuli and external stimuli, and this allows them to maintain homeostasis. Response to stimuli also accounts for the behavior of organisms; see p. 11. Behavior evolves through natural selection in the same manner as do anatomical features.
6. **Life forms ecosystems.** Interactions are a hallmark of living things. Cells interact within organisms, and populations interact in ecosystems. We could not exist without food produced by plants and without bacteria and fungi that decompose dead remains; see p. 12.
7. **Life evolves.** The history of life began with a common source, but as life reproduces it passes on genes that can mutate. Through mutations, advantages arise that are suited to the environment, and through natural selection they become more prevalent in a population. Adaptation to different environments accounts for the variety of life on Earth; see pp. 13–16.



1.10 Check Your Progress Describe how the hawk and her offspring illustrate the characteristics of life.

THE CHAPTER IN REVIEW

SUMMARY

Science Helps Us Understand the Natural World

1.1 Scientists use a preferred method

- Biology is the scientific study of life.
- The scientific method consists of four steps:
  - making **observations** using both our senses and special instruments
  - formulating a possible explanation, called a **hypothesis,** by using inductive reasoning
  - doing **experiments** that involve an **experimental variable, test groups,** and a **control group** that is not exposed to the experimental variable. Alternatively, scientists can simply make further observations. When doing experiments, scientists sometimes work with a **model.**
  - coming to a **conclusion** based on **data** as to whether the hypothesis is supported or not.
- A **scientific theory** is a major concept supported by many observations, experiments, and data.

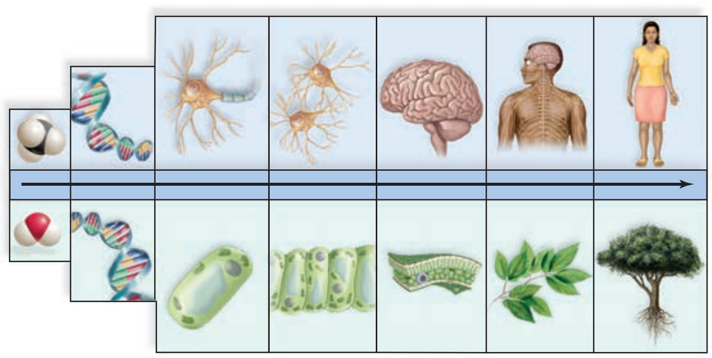
1.2 Control groups allow scientists to compare experimental results

- In a scientific experiment involving the use of a synthetic nitrogen fertilizer versus a **legume** (pigeon pea) to enrich the soil, the control pots produced a greater yield than those utilizing the legume. After three years, however, a winter wheat/pigeon pea rotation out-performed the control pots and those that were fertilized with a synthetic nitrogen fertilizer.

Organisms Are Composed of Cells

1.3 Cells are the fundamental unit of living things

- Biological organization extends from the molecules in cells to the organism and beyond.



- The **cell theory** states that **cells,** the fundamental units of life, come from other cells as **reproduction** of cells and the organism occurs.

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- In cells, **atoms** combine to form **molecules;** similar cells make up a **tissue;** and tissues compose **organs** that work together in **organ systems.** Organ systems work together in an **organism.**
- Cells and organisms acquire materials and energy from the environment to maintain their organization.
  - **Energy** is the capacity to do work.
  - **Metabolism** carries out chemical reactions.
  - **Photosynthesis** allows plants to capture solar energy and produce nutrients that sustain all organisms.

Genes Control the Traits of Organisms

1.4 Organisms have a genetic inheritance

- The **gene theory** tells us that **genes** are hereditary units composed of **DNA.**
- Genes control the structure and function of cells and organisms by coding for cellular molecules **(proteins).**
- Because genes can **mutate,** each organism has it own particular sequence of DNA nucleotides.
- The gene theory has been very fruitful, yielding many practical applications, such as those listed on page 10.

Organisms Are Homeostatic

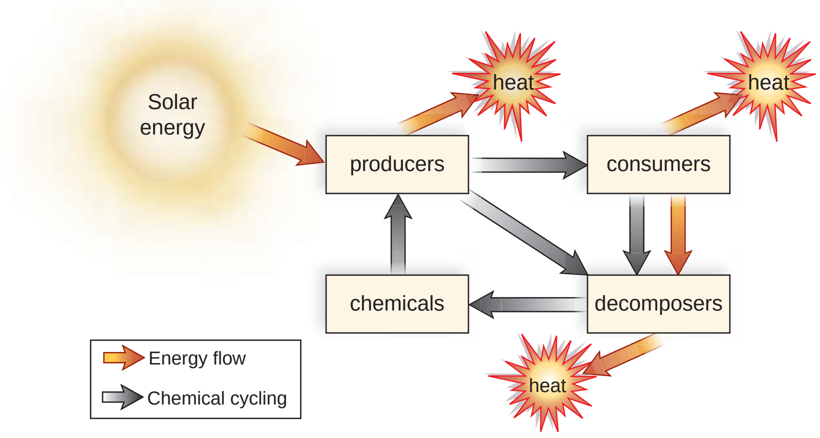
1.5 Organisms regulate their internal environment

- The **theory of homeostasis** states that organisms and cells have mechanisms that keep the internal environment relatively constant. Only then can life continue.
- Homeostasis involves the use of sense receptors to monitor the external and internal environment.
- Organisms can respond to changes in the environment. For example, when plants turn toward sunlight, they acquire the energy they need to photosynthesize.

Organisms Live in Ecosystems

1.6 The biosphere is divided into ecosystems

- The theory of ecosystems says that within a local environment:
  - The members of each species are a population.
  - Populations form a community in which they interact with each other.
  - In a community, chemicals cycle and energy flows but does not cycle.
  - Chemical cycling requires interaction with the physical environment.



- Diverse ecosystems, including tropical rain forests and coral reefs, are being destroyed by human activities.

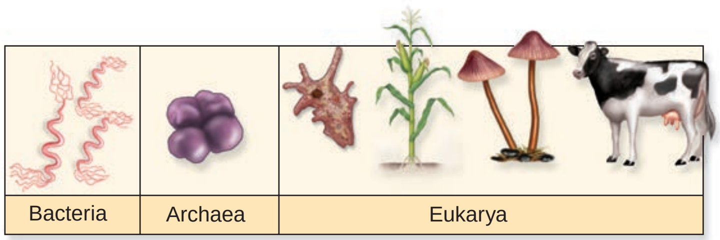
Organisms Are Related and Adapted to Their Environment

1.7 The ancestry of species can be determined

- The **theory of evolution** says that all species (living or extinct) can trace their ancestry to a common source.
- An **evolutionary tree** depicts the pattern of descent by way of **common ancestors.**

1.8 Evolutionary relationships help biologists group organisms

- **Taxonomy** is the classification of organisms according to the evolutionary relationships.
- The classification categories are **species** (least inclusive), **genus, family, order, class, phylum, kingdom,** and **domain** (most inclusive).
- There are three domains: **Bacteria, Archaea,** and **Eukarya.**



- Domain Archaea and domain Bacteria contain **prokaryotes** (organisms without a membrane-bounded nucleus).
- Domain Eukarya contains **eukaryotes** (organisms with a membrane-bounded nucleus).
- There are four major groups in domain Eukarya:
  - **Protists**—unicellular to multicellular organisms with various modes of nutrition
  - **Fungi**—molds and mushrooms
  - **Plants**—multicellular photosynthesizers
  - **Animals**—multicellular organisms that ingest food
- To classify an organism, two-part scientific names—**binomial nomenclature**—are used, consisting of the genus name and the **specific epithet.**

1.9 Evolution through natural selection results in adaptation to the environment

- The theory of evolution also says that modifications are introduced as evolution occurs, and if these modifications assist **adaptations,** they become more common through **natural selection.** The result is a wide variety of life-forms on Earth, each adapted to a different environment.

1.10 Evolution from a common ancestor accounts for the characteristics of life

- Organisms have shared characteristics because of common descent. Life is organized, uses materials and energy, reproduces, is homeostatic, responds to stimuli, forms ecosystems, and evolves.

TESTING YOURSELF

Science Helps Us Understand the Natural World

1. Which of the following words would not be part of a conclusion?
   a. proof
   b. support
   c. rejection
   d. All can be part of a conclusion.

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2. Which term and definition are mismatched?
   a. data—factual information
   b. hypothesis—the idea to be tested
   c. conclusion—what the data tell us
   d. All of these are properly matched.
3. Which of these describes the control group in the pigeon pea/winter wheat experiment? The control group was
   a. planted with pigeon peas.
   b. treated with nitrogen fertilizer.
   c. not treated.
   d. not watered.
   e. Both c and d are correct.
4. **THINKING CONCEPTUALLY** What's the relationship between the scientific method and the five theories on which this book is based?

Organisms Are Composed of Cells

5. The level of organization that includes cells of similar structure and function is
   a. an organ. c. an organ system.
   b. a tissue. d. an organism.
6. Which sequence represents the correct order of increasing complexity in living systems?
   a. cell, molecule, organ, tissue
   b. organ, tissue, cell, molecule
   c. molecule, cell, tissue, organ
   d. cell, organ, tissue, molecule
7. All of the chemical reactions that occur in a cell are called
   a. homeostasis. c. heterostasis.
   b. metabolism. d. cytoplasm.
8. The process of turning solar energy into chemical energy is called
   a. work. c. photosynthesis.
   b. metabolism. d. respiration.

Genes Control the Traits of Organisms

9. Genes are
   a. present in eukaryotes but not in prokaryotes.
   b. composed of RNA and DNA.
   c. passed on from cell to cell and from organism to organism.
   d. All of these are correct.
10. Genes
   a. code for proteins.
   b. can mutate.
   c. are always composed of four nucleotides.
   d. All of these are correct.
11. **THINKING CONCEPTUALLY** What's the relationship between genes and the diversity of life?

Organisms Are Homeostatic

12. Which of the following are a part of homeostasis?
   a. Animals keep their internal temperature relatively constant.
   b. Your blood cell count is always about the same.
   c. Certain organs, such as the kidneys, excrete wastes.
   d. Plants are able to turn toward the sun.
   e. All of these are correct.
13. To remain homeostatic, organisms need to
   a. be multicellular.
   b. acquire material and energy from the environment.
   c. have a nervous system.
   d. respond to stimuli.
   e. Both b and d are correct.

Organisms Live in Ecosystems

14. Which sequence represents the correct order of increasing complexity?
   a. biosphere, community, ecosystem, population
   b. population, ecosystem, biosphere, community
   c. community, biosphere, population, ecosystem
   d. population, community, ecosystem, biosphere
15. In an ecosystem, energy
   a. flows and nutrients cycle.
   b. cycles and nutrients flow.
   c. and nutrients flow.
   d. and nutrients cycle.
16. An example of chemical cycling occurs when
   a. plants absorb solar energy and make their own food.
   b. energy flows through an ecosystem and becomes heat.
   c. hawks soar and nest in trees.
   d. death and decay make inorganic nutrients available to plants.
   e. we eat food and use the nutrients to grow or repair tissues.
17. Energy is brought into ecosystems by which of the following?
   a. fungi and other decomposers
   b. cows and other organisms that graze on grass
   c. meat-eating animals
   d. organisms that photosynthesize, such as plants
   e. All of these are correct.
18. **THINKING CONCEPTUALLY** How is a college campus, which is composed of buildings, students, faculty, and administrators, like an ecosystem?

Organisms Are Related and Adapted to Their Environment

19. Organisms are related because they
   a. all have the same structure and function.
   b. share the same characteristics.
   c. can all trace their ancestry to a common source.
   d. all contain genes.
20. An evolutionary tree
   a. shows common ancestors.
   b. depicts the history of a group of organisms.
   c. is based on appropriate data.
   d. shows how certain organisms are related.
   e. All of these are correct.
21. Classification of organisms reflects
   a. similarities.
   b. evolutionary history.
   c. Neither a nor b is correct.
   d. Both a and b are correct.
22. Which of these exhibits an increasingly more inclusive scheme of classification?
   a. kingdom, phylum, class, order
   b. phylum, class, order, family
   c. class, order, family, genus
   d. genus, family, order, class
23. Humans belong to the domain
   a. Archaea. c. Eukarya.
   b. Bacteria. d. None of these are correct.
24. In which group are you most likely to find unicellular organisms?
   a. Protists c. Plantae
   b. Fungi d. Animalia
25. The second word of a scientific name, such as *Homo sapiens*, is the
   a. genus. d. species.
   b. phylum. e. family.
   c. specific epithet.

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26. Modifications that make an organism suited to its way of life are called
   a. ecosystems.
   b. populations.
   c. adaptations.
   d. None of these are correct.
27. **THINKING CONCEPTUALLY** Give evidence to support the phrase "Evolution is the unifying theory of biology."

For questions 28–31, match each item to a characteristic of life in the key.

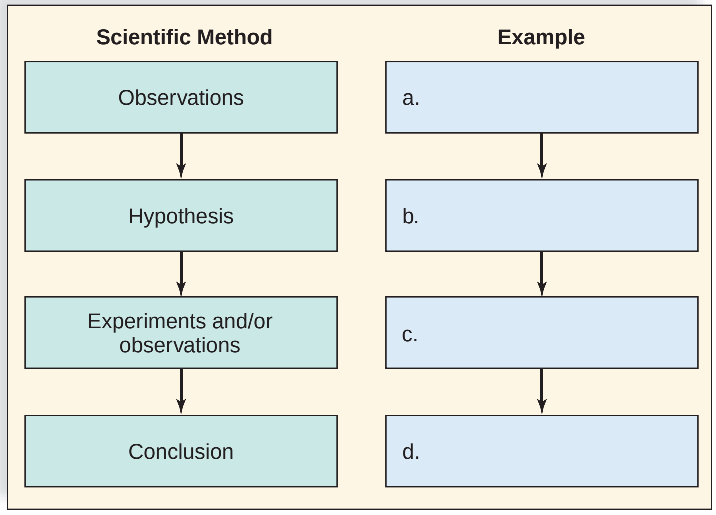
KEY:

a. is organized
b. uses materials and energy
c. reproduces
d. is homeostatic
e. responds to stimuli
f. forms ecosystems
g. evolves

28. organisms exhibit behavior
29. populations interact
30. giraffes produce only giraffes
31. common descent with modification

THINKING SCIENTIFICALLY

1. An investigator spills dye on a culture plate and notices that the bacteria live despite exposure to sunlight. He decides to test whether the dye is protective against ultraviolet (UV) light. He exposes to UV light one group of culture plates containing bacteria and dye and another group containing only bacteria. The bacteria on all plates die. Complete the following diagram to identify the steps of his investigation.
2. You want to grow large tomatoes and notice that a name-brand fertilizer claims to yield larger produce than a generic brand. How would you test this claim?



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Enhance your study with animations that bring concepts to life and practice tests to assess your understanding. Your instructor may also recommend the interactive eBook, individualized learning tools, and more.

CONNECTING THE CONCEPTS

The scientific method consists of making observations, formulating a hypothesis, testing the hypothesis, and coming to a conclusion on the basis of the results (data). The conclusions of many studies have allowed scientists to develop the five theories (cell theory, gene theory, theory of homeostasis, theory of ecosystems, and theory of evolution) on which this book is based. Theories are conceptual schemes that tell us how the world works. All theories of biology are related. For example, the gene theory is connected to the theory of evolution because mutations create differences between the members of a population. Better-adapted members have the opportunity through natural selection to reproduce more, and in that way a species becomes adapted to its environment.

Any two theories are related. For example, evolution is also connected to the theory of ecosystems because, as natural selection occurs, species become adapted to living in a particular ecosystem. We can connect this observation to the cell theory because, if a gazelle's nerve cells can conduct nerve impulses faster to its muscle cells than a lion's nerve cells, the gazelle is more likely to escape capture.

In exploring the theories, we have also discussed the characteristics of life. The cell theory taught us that all organisms are composed of cells and that cells are the fundamental units of life. The theory of homeostasis tells us that all organisms have mechanisms that allow them to keep their internal environment relatively constant. The gene theory tells us all organisms have genes, hereditary units that undergo mutations leading to the variety of life. Even so, all life-forms share similar characteristics because they can trace their ancestry to a common source as stated by the theory of evolution. All life-forms live in ecosystems where interactions allow them to acquire the materials and energy they need to continue their existence. Human beings are also dependent on ecosystems, and when they preserve the biosphere, they are preserving their own existence as well.

PUT THE PIECES TOGETHER

1. Give your own example (not taken from this reading) to show that two theories are related.
2. Explain in your own words how bacteria become resistant to an antibiotic.

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4

Structure and Function of Cells

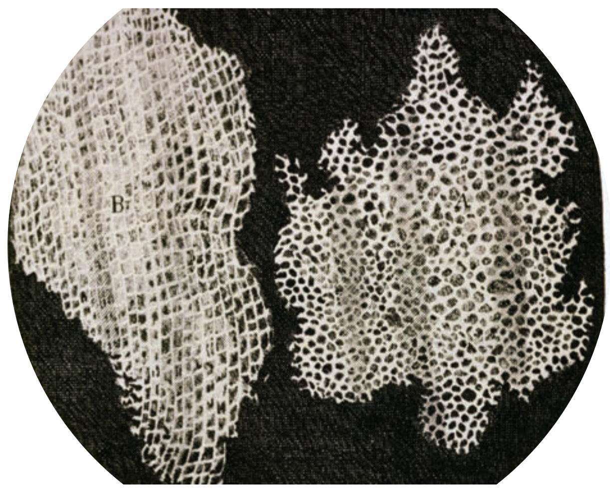
CHAPTER OUTLINE

APPLICATIONS

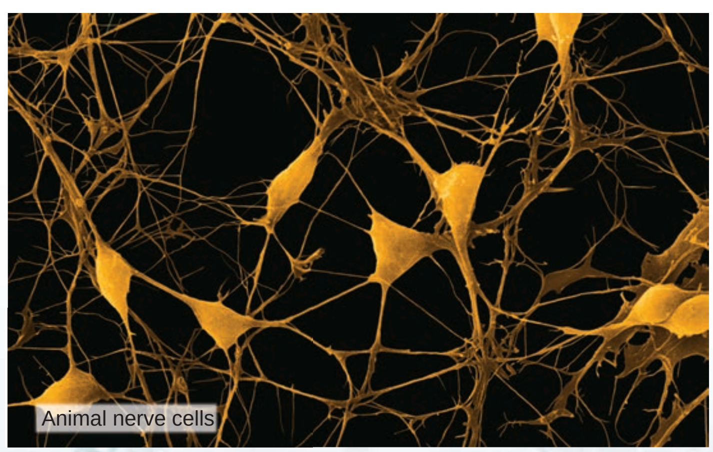
Cells: What Are They?

Imagine that you have never taken a biology course, and you are alone in a laboratory with a bunch of slides of plant and animal tissues and a microscope. The microscope is easy to use, and soon you are able to focus it and begin looking at the slides.

Your assignment is to define a cell. In order not to panic, you idly look at one slide after another, letting your mind wander. Was this the way Robert Hooke felt back in the seventeenth century, when he coined the word "cell"? What did he see? Actually, Hooke was using a light microscope, as you are, when he happened to look at a piece of cork. He drew what he saw like this:



Hooke saw almost nothing except for outlines, which we know today are the cell walls of plant cells. Similarly, you can make out the demarcations between onion root cells in the micrograph on page 63. After comparing these to the nerve cells below, you might conclude that a cell is an entity, a unit of a larger whole.



Animal nerve cells

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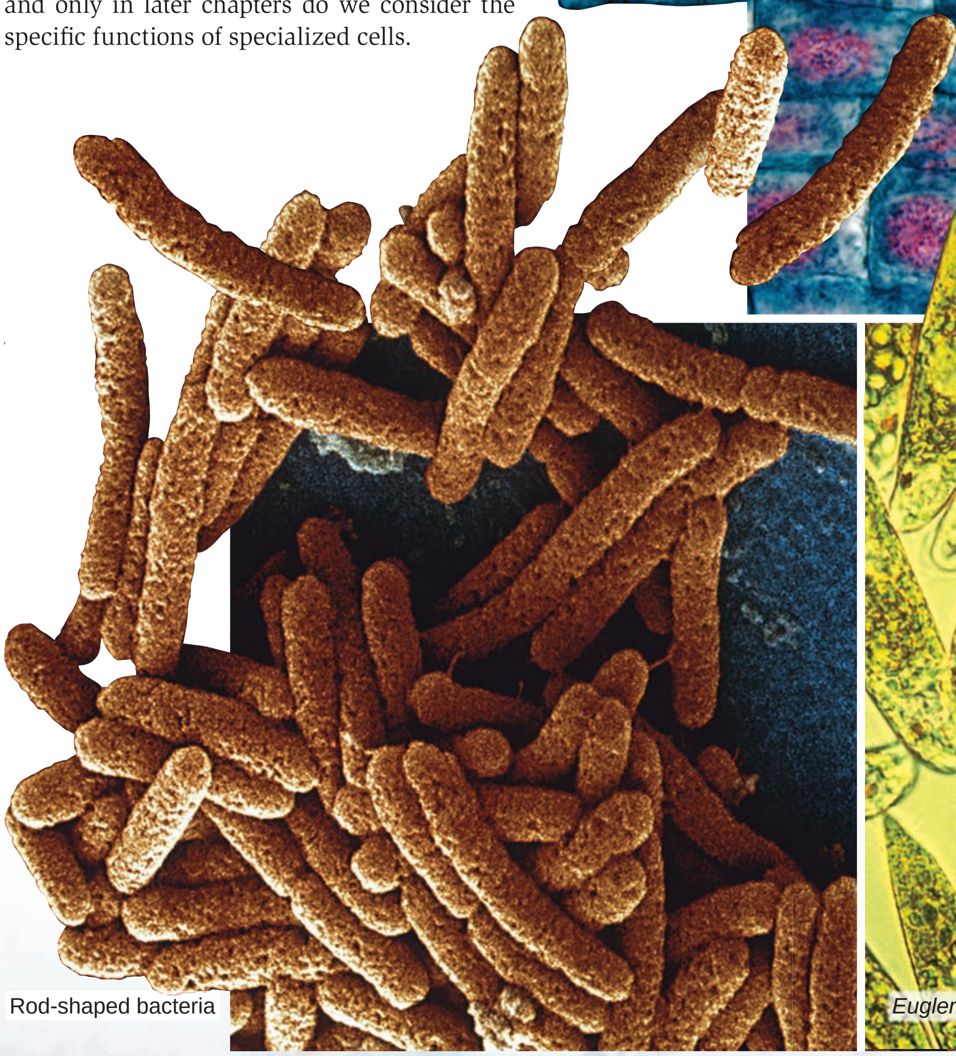
Once you had such a definition for a cell, you might be able to conclude that cells are present in all the slides at your disposal—as in all the micrographs on these pages. But it certainly would take a gigantic leap to hypothesize that all organisms are composed of cells, and this didn't occur until almost 200 years after Hooke used the term cell. You can appreciate that science progresses slowly, little by little, and that a theory, such as the cell theory, becomes established only when an encompassing hypothesis is never found to be lacking. Indeed, it was only when Matthias Schleiden always saw cells in plant tissues, and Theodor Schwann always saw cells in animal tissues, that they concluded, respectively, in the 1830s that plants and animals are composed of cells.

This chapter begins with an explanation of the cell theory and then considers the general characteristics of cells. The cell theory was formulated before the electron microscope was invented and before the biochemical techniques now used to study cells were developed. These improvements in technology tells us how the structure of cells is suited to carrying on the functions necessary to staying alive. These activities are common to all cells, and only in later chapters do we consider the specific functions of specialized cells.


Onion root cells


Rod-shaped bacteria


Euglena, a protist

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Cells Are the Basic Units of Life

Learning Outcomes

- Cite three tenets of the cell theory. (4.1)
- Explain why cells are so small. (4.2)
- Compare and contrast prokaryotic and eukaryotic cells. (4.3, 4.4)

All organisms are composed of cells, which are about the same small size whether present in an ant or a whale. Surface-to-volume relationships explain why most cells can be measured in micrometers. The two major types of cells—prokaryotic and eukaryotic—differ in complexity, but even so both contain DNA and have a cytoplasm bounded by a plasma membrane.

4.1 All organisms are composed of cells

The **cell theory** states that:

1. ***A Cell Is the Basic Unit of Life*** This means that nothing smaller than a cell is alive. A unicellular organism exhibits the characteristics of life we discussed in Chapter 1. No smaller unit exists that is able to reproduce, respond to stimuli, remain homeostatic, grow and develop, take in and use materials from the environment, and adapt to the environment. In short, life has a cellular nature. On this basis, we can make two other deductions.
2. ***All Living Things Are Made Up of Cells*** While it may be apparent that a unicellular organism is a cell, what about more complex organisms? Lilacs and rabbits as well as other visible organisms are multicellular. **Figure 4.1A** illustrates that a lilac leaf is composed of cells, and **Figure 4.1B** illustrates that the intestinal lining of a rabbit is composed of cells. Is there any tissue in these organisms that is not composed of cells? For example, you might be inclined to say that bone does not contain cells. But if you were to examine bone tissue under a microscope, you would see that it, too, is composed of cells. Cells have distinct forms—a bone cell looks quite different from a nerve cell, and they both look quite different from the cell of a lilac leaf. Although cells are specialized in structure and function, they have certain parts in common. This chapter discusses those common components.
3. ***New Cells Arise Only from Preexisting Cells*** This statement wasn't readily apparent to early investigators, who believed that organisms could arise from dirty rags, for example. Today, we know you cannot get a new lilac bush or a new rabbit without preexisting lilacs and rabbits. When lilacs, rabbits, or humans reproduce, a sperm cell joins with an egg cell to form a zygote, which is the first cell of a new multicellular organism.

4.1 Check Your Progress **A cell is alive, but its parts are not alive. Explain.**

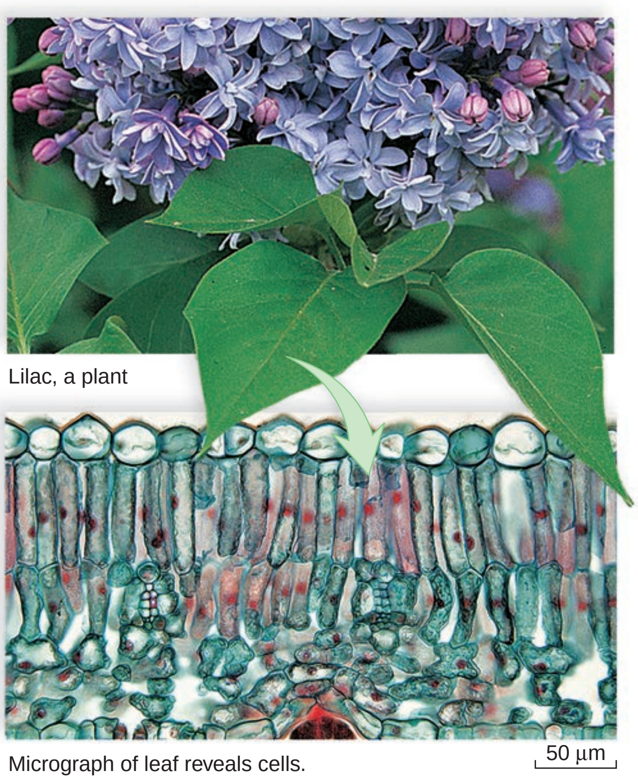
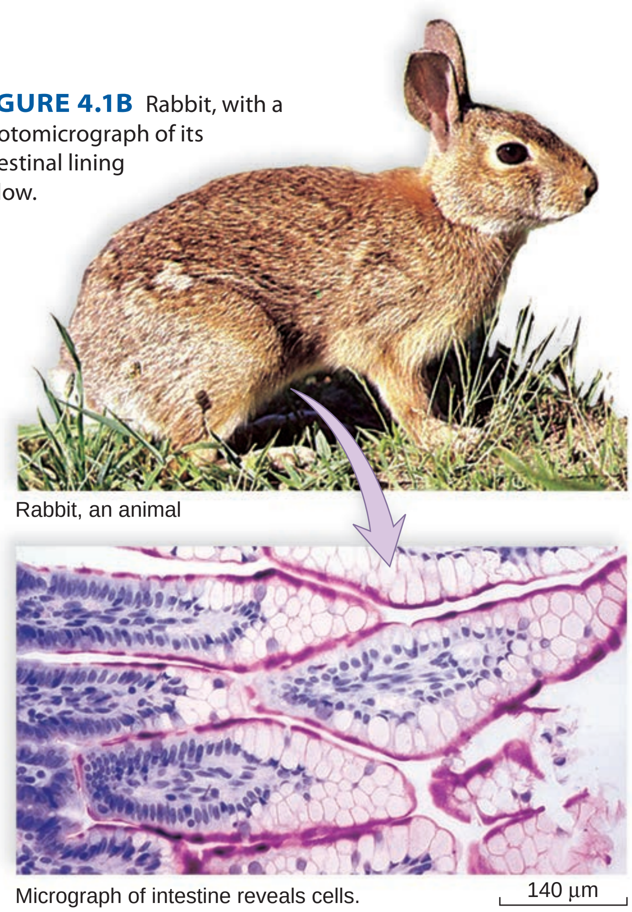


FIGURE 4.1A Lilac leaf, with a photomicrograph below.

FIGURE 4.1B Rabbit, with a photomicrograph of its intestinal lining below.



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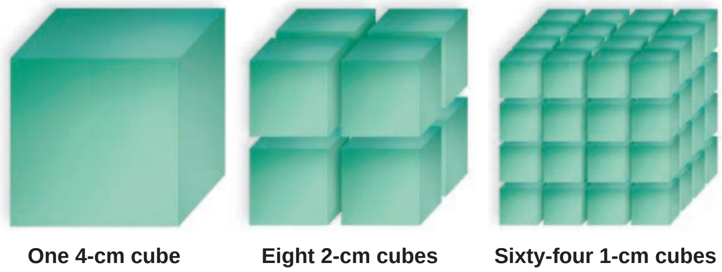
4.2 Metabolically active cells are small in size

Cells tend to be quite small. A frog's egg, at about 1 millimeter (mm) in diameter, is large enough to be seen by the human eye. But most cells are far smaller than 1 mm; some are even as small as 1 micrometer (μm)—one thousandth of a millimeter. Cell structures and biomolecules that are smaller than a micrometer are measured in terms of nanometers (nm). **Figure 4.2A** outlines the visual range of the eye, the light microscope, and the electron microscope. How Science Progresses on page 66 explains why the electron microscope allows us to see so much more detail than the light microscope does.

Why are cells so small? To answer this question, consider that a cell needs a surface area large enough to allow sufficient nutrients to enter and to rid itself of wastes. Small cells, not large cells, are more likely to have this adequate surface area per volume. Consider a balloon: The air in the balloon is the volume, and the balloon's skin is its surface area. A larger balloon has more volume, as you can appreciate by trying to blow up a large balloon compared to a small balloon. How might you appreciate the amount of surface area per volume? **Figure 4.2B** shows one way because it calculates the surface area per volume for different-sized cubes. Cutting a large cube into smaller cubes provides a lot more surface area per volume. The calculations show that a 4-cm cube has a **surface-area-to-volume ratio** of only 1.5:1, whereas a 1-cm cube has a surface-area-to-volume ratio of 6:1.

We would expect, then, that actively metabolizing cells would have to remain small. A chicken's egg is several centimeters in diameter, but the egg is not actively metabolizing. Once the egg is incubated and metabolic activity begins, the egg divides repeatedly without growth. Cell division restores the amount of surface area needed for adequate exchange of materials.



Total surface area (height × width × number of sides × number of cubes)		
96 cm^2	192 cm^2	384 cm^2
Total volume (height × width × length × number of cubes)		
64 cm^3	64 cm^3	64 cm^3
Surface-area-to-volume ratio per cube (surface area ÷ volume)		
1.5:1	3:1	6:1

FIGURE 4.2B Surface-area-to-volume relationships.

Further, cells that specialize in absorption have modifications that greatly increase the surface-area-to-volume ratio of the cell. The cells along the surface of the intestinal wall have surface foldings called microvilli (sing., microvillus) that increase their surface area. Nerve cells and some large plant cells are long and thin, and this increases the ratio of plasma membrane to cytoplasm. Nerve cells are shown on page 62.

4.2 Check Your Progress **Why is your body made up of multitudes of small cells, instead of a single large cell?**

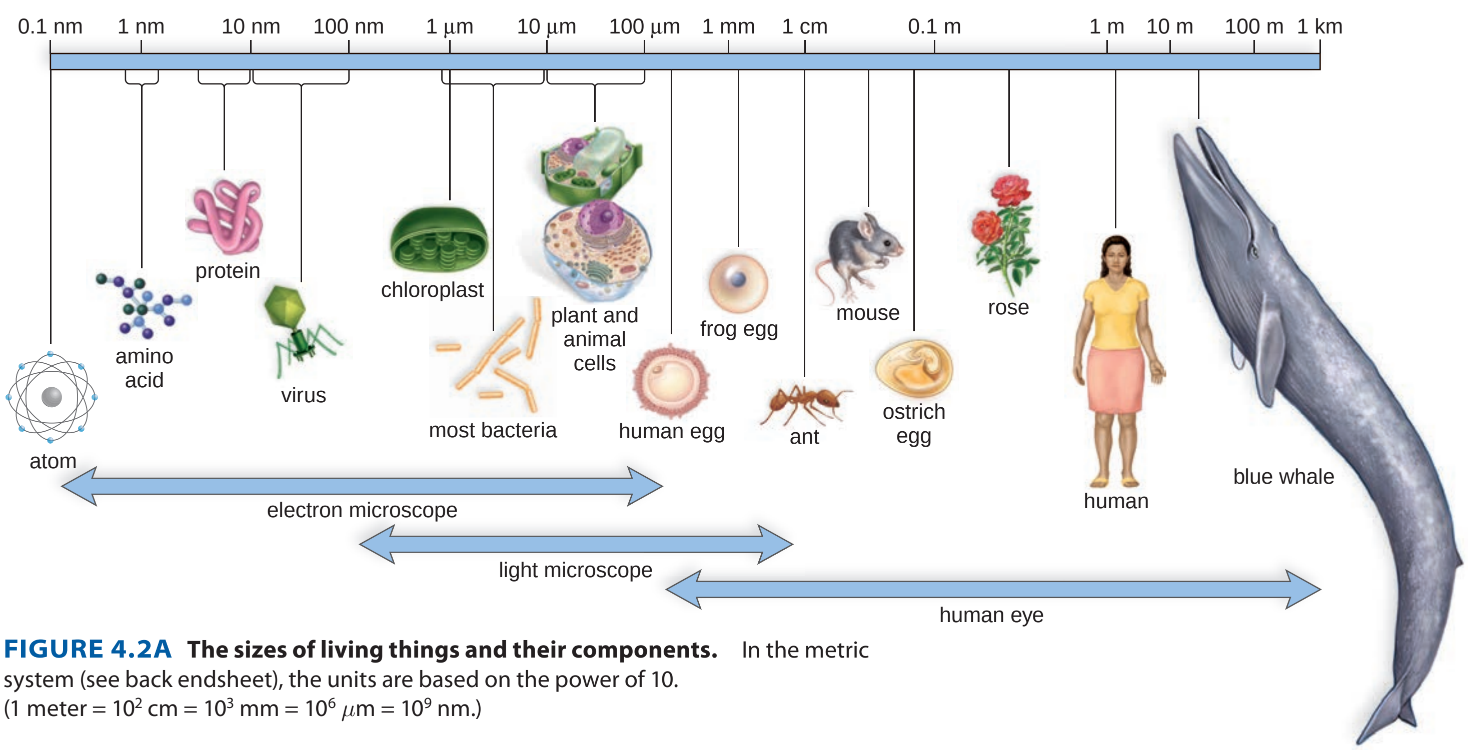


FIGURE 4.2A **The sizes of living things and their components.** In the metric system (see back endsheet), the units are based on the power of 10. (1 meter = 10^2 cm = 10^3 mm = 10^6 μm = 10^9 nm.)

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HOW SCIENCE PROGRESSES *Application*

4A Microscopes Allow Us to See Cells

Because cells are so small, it is best to study them microscopically. A magnifying glass containing a single lens is the simplest version of a light microscope. However, such a simple device is not powerful enough to be of much use in examining cells. The **compound light microscope** is much more suitable. It has superior magnifying power because it uses a system of multiple lenses. As you can see in **Figure 4A*a*,** a condenser lens focuses the light into a tight beam that passes through a thin specimen (such as a unicellular amoeba, a drop of blood or a thin slice of an organ). An objective lens magnifies an image of the specimen, and another lens, called the ocular lens, magnifies it yet again. It is the image from the ocular lens that is viewed with the eye. The most commonly used compound light microscope is called a bright-field microscope, because the specimen, which is typically stained, appears dark against a light background.

The compound light microscope is widely used in research, clinical, and teaching laboratories. However, the use of light to produce an image means that the ability to view two objects as separate—the resolution—is not as good as with an electron microscope. The resolution limit of a compound light microscope is 0.2 μm, which means that objects less than 0.2 μm apart appear as a single object. Although there is no limit to the magnification that could be achieved with a compound light microscope, there is a definite limit to the resolution.

The wavelength of light is an important consideration in obtaining the best possible resolution with a compound light microscope. The shorter the wavelength of light, the better the resolution. This is why many compound light microscopes are equipped with blue filters. The shorter wavelength of blue light compared to white light improves resolution.

An electron microscope can produce finer resolution than a light microscope because, instead of using light, it fires a beam of electrons at the specimen. Electrons have a shorter wavelength than does light. The essential design of an electron microscope is similar to that of a compound light microscope, but its lenses are made of electromagnets, instead of glass. Because the human eye cannot see at the wavelengths of electrons, the images produced by electron microscopes are projected onto a screen or viewed on a television monitor.

There are two types of electron microscopes: the transmission electron microscope and the scanning electron microscope. These microscopes didn't become widely used until about 1970. A **transmission electron microscope** passes a beam of electrons through a specimen (Fig. 4A*b*). Because electrons do not have much penetrating ability, the section must be very thin—usually between 50 and 150 nm. The transmission electron microscope can discern fine details, with a limit of resolution around 1.0 nm and a magnifying power up to 200,000 times larger than the actual size. A **scanning electron microscope** does not pass a beam through a specimen; rather, it collects and focuses electrons that are scattered from the specimen's surface and generates an image with a distinctive three-dimensional appearance (Fig. 4A*c*).

Scientists often preserve microscopic images; these are referred to as micrographs. A captured image from a light microscope is termed a light micrograph (LM), or a photomicrograph. There are also transmission electron micrographs (TEM) and scanning electron micrographs (SEM). The latter two are black-and-white in their original form, but are often colorized for clarity using a computer.

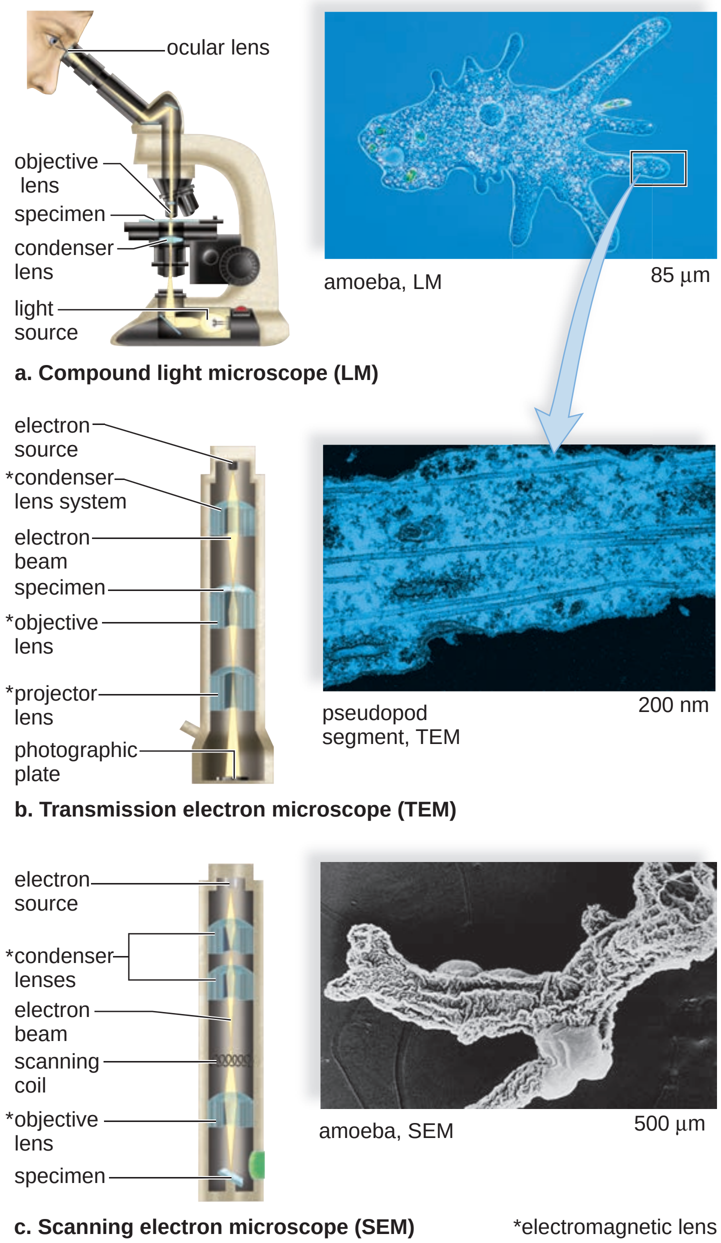

FIGURE 4A Comparison of three microscopes.

FORM YOUR OPINION

1. How would you convince a friend that what we see in micrographs actually exists?
2. TEMs are colorless but can have color added to them. Do you think color enhancement of TEMs borders on misrepresentation? Why or why not?

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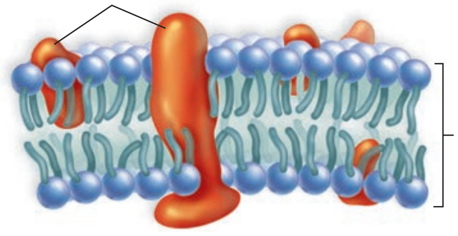
4.3 Prokaryotic cells evolved first

Fundamentally, two different types of cells exist. **Prokaryotic cells** (*pro*, before, and *karyon*, nucleus) are so named because they lack a membrane-bounded nucleus. The other type of cell, called a eukaryotic cell, has a nucleus. Prokaryotic cells are miniscule in size compared to eukaryotic cells (**Fig. 4.3A**). Prokaryotes are present in great numbers in the air, in bodies of water, in the soil, and also in and on other organisms.

As discussed on page 14, prokaryotic cells are divided into two groups, largely based on DNA evidence. These two groups are so biochemically different that they have been placed in separate domains, called domain **Bacteria** and domain **Archaea. Figure 4.3B** shows the generalized structure of a bacterium.

Like a eukaryotic cell, a bacterium is full of a semifluid substance called **cytoplasm** that is bounded by a **plasma membrane.** The plasma membrane is a phospholipid bilayer (see Fig. 3.7) with embedded proteins.



The plasma membrane has the important function of regulating the entrance and exit of substances into and out of the cytoplasm. After all, the cytoplasm has a normal composition that needs to be maintained. It contains thousands of **ribosomes** where protein synthesis ocurs. The long, looped chromosome of a prokaryotic cell is located within a region of the cytoplasm known as a **nucleoid.** Bacteria reproduce by splitting in two, and each new cell gets a copy of the chromosome. They can share DNA with other bacteria by various means. Cyanobacteria (*cyan*, blue-green) are able to photosynthesize in the same manner as plants because they have light-absorbing chlorophyll on their internal membranes.

In addition to the plasma membrane, bacteria have a **cell wall,** which helps maintain the shape of the cell. The cell wall may in turn be surrounded by a **capsule.** Many short, hollow protein rods called **pili** project through the cell wall. Pili attach the cell to solid substances and produce a slime that coats your teeth, rocks at the bottom of lakes, and the hulls of ships, for example. Motile bacteria usually have long, very thin flagella (sing., flagellum), which rotate like propellers, rapidly moving the bacterium in a fluid medium.

Bacteria are well known for causing serious diseases, such as tuberculosis, anthrax, tetanus, throat infections, and gonorrhea. However, they are important to the environment because they decompose the remains of dead organisms and contribute to the cycling of chemicals in ecosystems. Also, their great ability to synthesize molecules can be put to use for the manufacture of all sorts of products, from industrial chemicals to foodstuffs and drugs.

▶ **4.3 Check Your Progress** **Why can't you define or recognize a cell by the presence of a nucleus?**

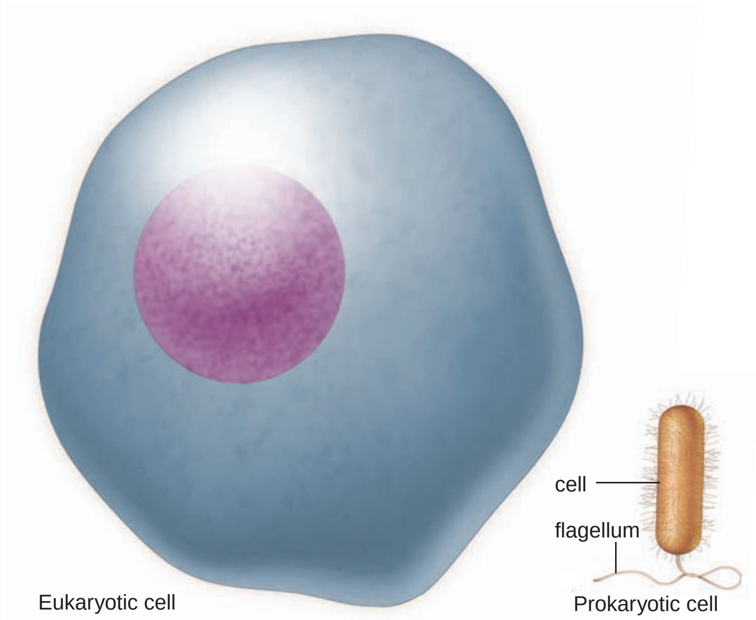


FIGURE 4.3A Eukaryotic cells are much larger than prokaryotic cells.

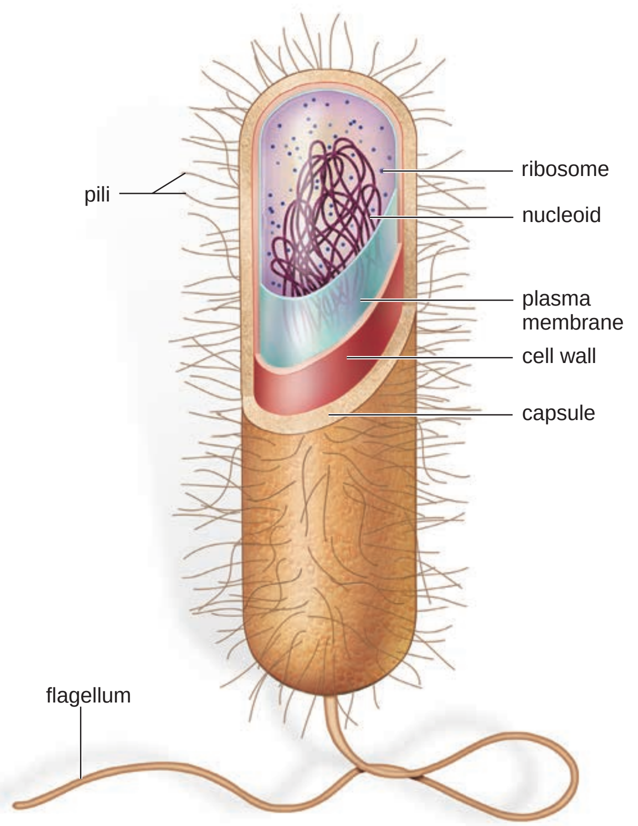


FIGURE 4.3B A prokaryotic cell is structurally simple but metabolically complex.

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4.4 Eukaryotic cells contain specialized organelles: An overview

Eukaryotic cells (*eu,* true, and *karyon,* nucleus) have a membrane-bounded **nucleus,** which houses their DNA. As depicted in Figure 1.8D, protists, fungi, plants, and animals are the groups of organisms that have eukaryotic cells and are in the domain **Eukarya,** the third domain of life.

Eukaryotic cells are much larger than prokaryotic cells, and therefore they have less surface area per volume than prokaryotic cells (see Fig. 4.2B). This disadvantage has been solved because the cells are compartmentalized—they have compartments. Just like a house that has separate rooms, the compartments of a eukaryotic cell are specialized for particular functions. In the kitchen of a house are utensils, appliances, and counters necessary for preparing and serving meals, while a bedroom contains personal effects and furniture for sleeping and storing clothes. Similarly, a cell contains **organelles** (meaning "little organs") that are specialized and only perform specific functions. The organelles are located within the cytoplasm, a semifluid interior bounded by a plasma membrane. As in prokaryotic cells, the plasma membrane is a phospholipid bilayer that contains proteins, shown in the circular blow-up of **Figure 4.4A.**

Eukaryotic cells are rich in membrane, and most organelles are membranous. Originally, the term organelle referred only to membranous structures, but we will use it to include any well-defined subcellular structure. By that definition, the little particles called ribosomes are also organelles. At first it might seem difficult to learn the names and functions of all the structures in plant and animal cells. One technique that will help is to have a mental image of the structure and then discover its function. So in **figures** 4.4A and **4.4B,** first look at the structure and then follow the leader back to its name and function. A well-known truism in biology states, "Structure suits function." Why might that be? In the course of evolution, those organisms whose cells possessed organelles suited to their function were more likely to have surviving offspring, and slowly over time all organisms of that group had such cells and organelles.

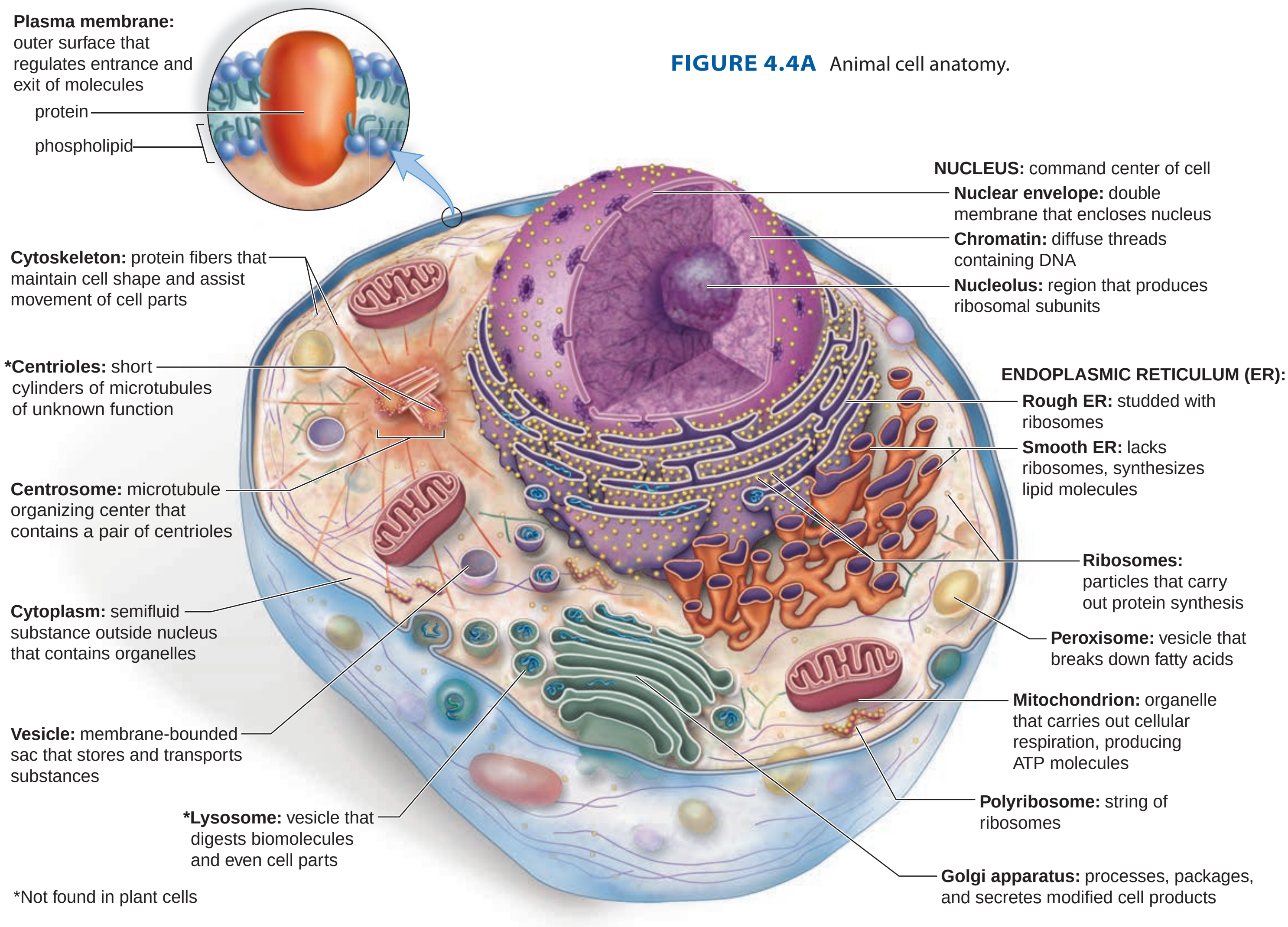

FIGURE 4.4A Animal cell anatomy.

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In this chapter we are going to concentrate on aspects of structure and function common to both animal and plant cells. Both types of cells have a nucleus that houses double stranded DNA as their genetic material and ribosomes that carry on protein synthesis in the same manner, for example. The fundamental aspects of cellular organization and function do not vary between the two types of cells. Still, we have an opportunity in this chapter to point out how the two types of cells differ as listed in **Table 4.4.** The cell wall of plants is covered in chapter 5 because chapter 5 concerns the structure and function of cell surfaces. However, Table 4.4 will assist you in learning the major differences between animal and plant cells. The other cell structures (plasma membrane, nucleus, centrosome, endoplasmic reticulum, ribosomes, Golgi, peroxisomes, cytoskeleton) are present in both plant and animal cells).

The various cells in your body have the structures depicted in Figure 4.4A but many of your cells have additional structures and modifications to carry on particular functions. Similarly, the plants in your garden and the trees in your yard have cells with the structures shown in Figure 4.4B but they also have cells that are specialized in different ways. Multicellular organisms in particular have specialized cells and this leads to their diversity in form and capabilities.

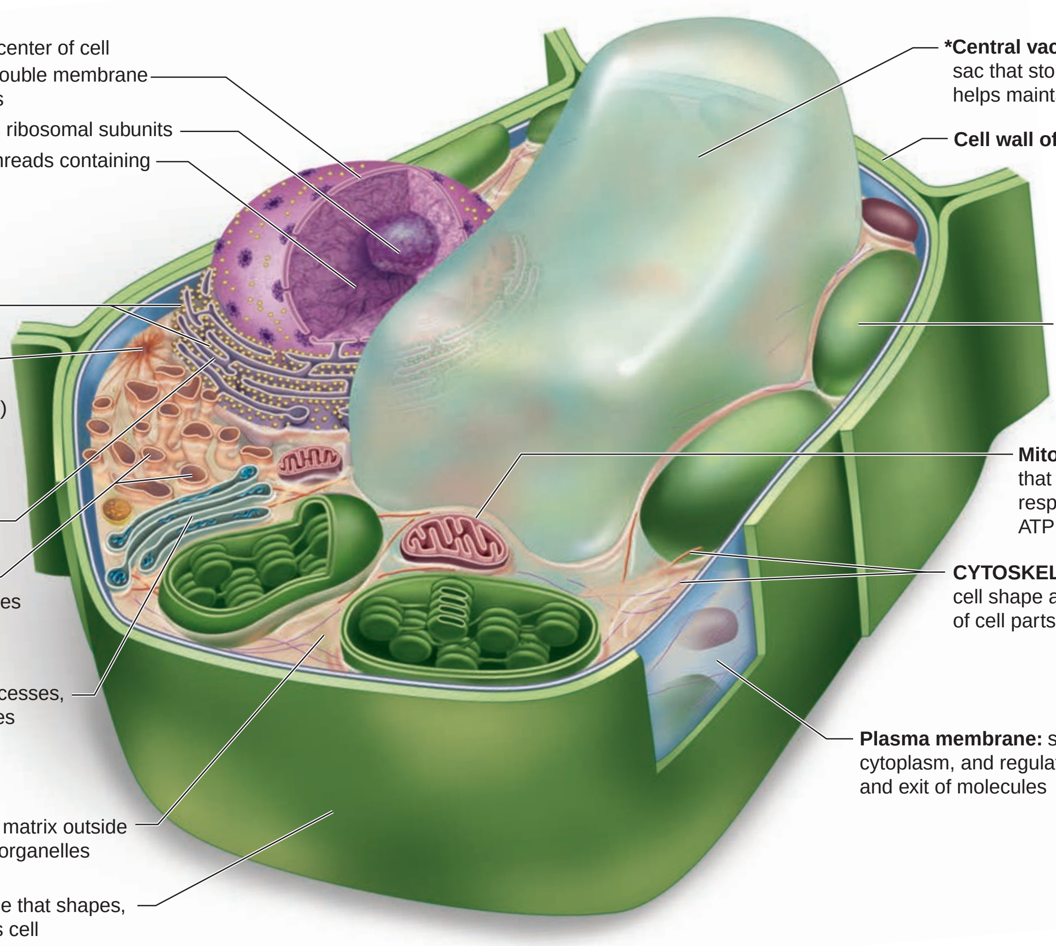
TABLE 4.4 Animal and Plant Cell Differences

Structure	Animal Cell	Plant Cell
Cell wall	No	Yes
Chloroplast	No	Yes
Lysosomes	Yes	No
Centrioles	Yes	No
Large central vacuole	No	Yes
Shape	Round	Rectangular

It's good to keep in mind as you study cell structures and their functions that despite their small size cells display all the characteristics of life we studied in chapter 1. This chapter tells you how they can accomplish this feat.

4.4 Check Your Progress **Explain why early investigators were unable to make out the detail illustrated in Figures 4.4A and 4.4B.**

FIGURE 4.4B Plant cell anatomy.



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Protein Synthesis Is a Major Function of Cells

Learning Outcomes

- Describe the structure of the nucleus, ribosomes, endoplasmic reticulum, and Golgi apparatus. (4.5–4.8)
- Explain how each of these organelles participates in protein synthesis. (4.5–4.8)

This part of the chapter discusses certain organelles of eukaryotic cells, namely the nucleus, the ribosomes, the endoplasmic reticulum, and the Golgi apparatus, which are all involved in producing proteins that may serve necessary functions in the cell or may be secreted out of the cell.

4.5 The nucleus contains the cell's genetic information

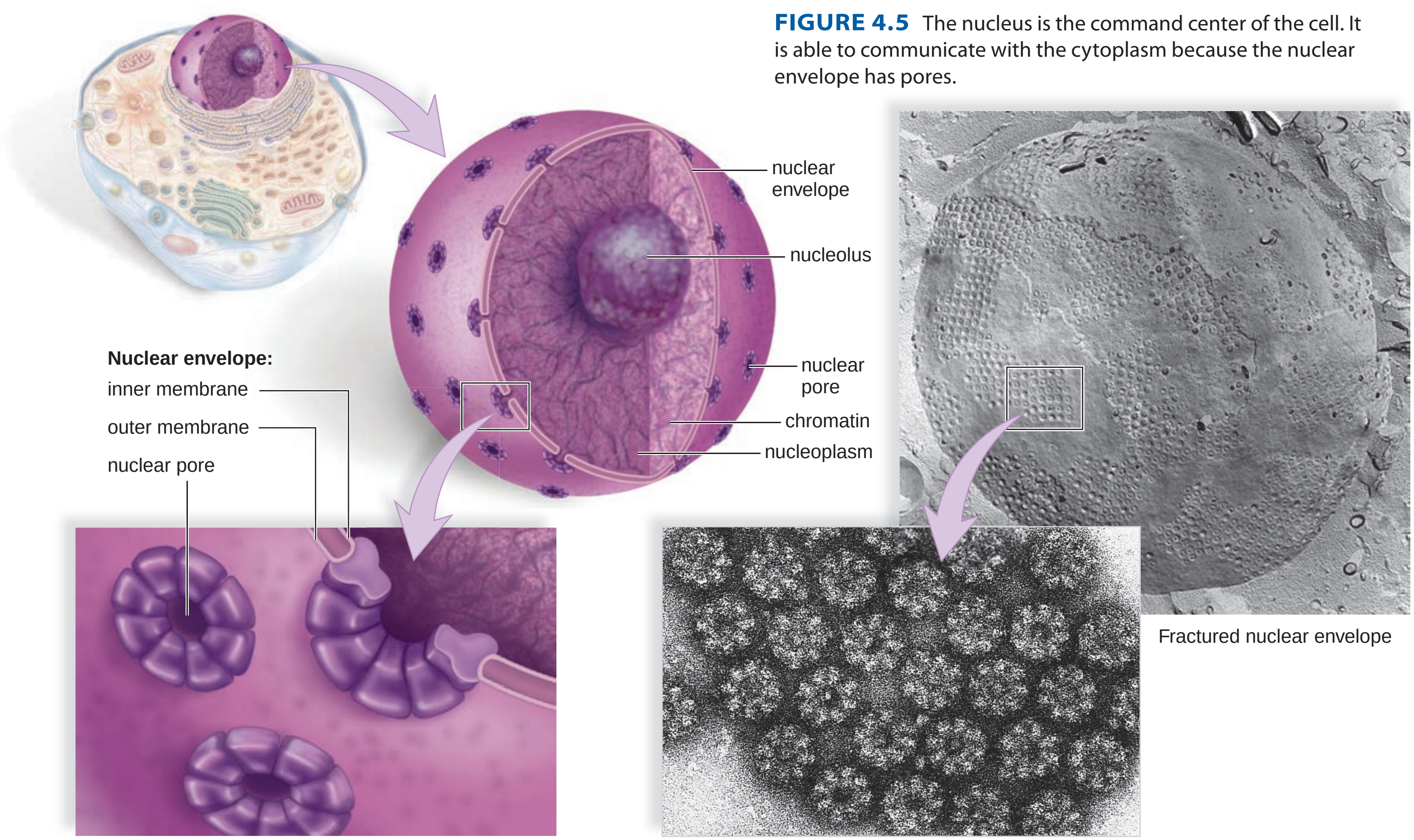
The nucleus is a prominent structure, in an eukaryotic cell (**Fig. 4.5**). It generally has an oval shape and is located near the center of a cell. The nucleus contains DNA, the genetic material that is passed from cell to cell and from generation to generation. DNA dictates which proteins a cell is to synthesize and these proteins determine the cell's structure and functions; therefore, the nucleus is the command center of a cell.

At the time of cell division, DNA and proteins are organized into the several **chromosomes** of an eukaryotic cell. Following cell division, the chromosomes become extended into **chromatin,** which looks grainy, but actually is a network of fine strands. A **nucleolus** is a dark region of chromatin where the subunits of ribosomes (discussed in Section 4.6) are produced.

The nucleus is separated from the cytoplasm by a double membrane known as the **nuclear envelope.** Even so, the nucleus communicates with the cytoplasm. The nuclear envelope has **nuclear pores** of sufficient size to permit the passage of ribosomal subunits out of the nucleus into the cytoplasm, and the passage of proteins from the cytoplasm into the nucleus. High-power electron micrographs show nonmembranous components associated with the pores that form a nuclear pore complex.

4.5 Check Your Progress **Which of the photomicrographs on pages 62 and 63 are cells with nuclei? Explain.**

FIGURE 4.5 The nucleus is the command center of the cell. It is able to communicate with the cytoplasm because the nuclear envelope has pores.



Nuclear pores, drawing

Nuclear pores, TEM

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4.6 The ribosomes carry out protein synthesis

Ribosomes are non-membrane-bounded particles that are especially abundant in cells that produce plentiful proteins. When you are going to make something, you usually need a surface on which to do your work. In the same manner, a cell uses ribosomes as a workbench for producing proteins.

Ribosomes are measured in nanometers, which means they are quite small; eukaryotic ribosomes are slightly larger than those in prokaryotes. In both types of cells, ribosomes are composed of two subunits, one large and one small.

In eukaryotic cells, some ribosomes occur freely within the cytoplasm, either singly or in groups called polyribosomes. Other ribosomes are attached to the **endoplasmic reticulum (ER),** a membranous system of flattened saccules (small sacs) and tubules, which is discussed more fully in Section 4.7.

Dressmakers usually use a pattern and directions that tell them how to make a garment. Similarly, a messenger RNA (mRNA) is a copy of a gene that tells a cell how to make the particular polypeptide of a protein at a ribosome. An mRNA leaves the nucleus by way of a nuclear pore and becomes attached to a ribosome. The mRNA copy of the gene indicates the correct sequence of amino acids for the particular polypeptide. Any slip-up in this process means the individual will have a nonworking protein and may become ill as a result!

Attachment of Ribosomes to the ER Proteins synthesized by cytoplasmic ribosomes often enter other organelles. Those synthesized by ribosomes attached to the ER end up in the interior of the ER. As shown in **Figure 4.6** 1 after the RNA copy of the gene leaves the nucleus and enters the cytoplasm, 2 it becomes attached to a ribosome, and polypeptide synthesis begins. 3 The ribosome becomes attached to the ER, and the polypeptide enters the interior of the ER. 4 The polypeptide folds into the shape of the protein inside the ER. Recall from Figure 3.10 that a protein can have up to four levels of organization. The shape of a protein is very important to its functioning appropriately.

▶ **4.6 Check Your Progress** **What two functions do the nuclear pores play in protein synthesis?**

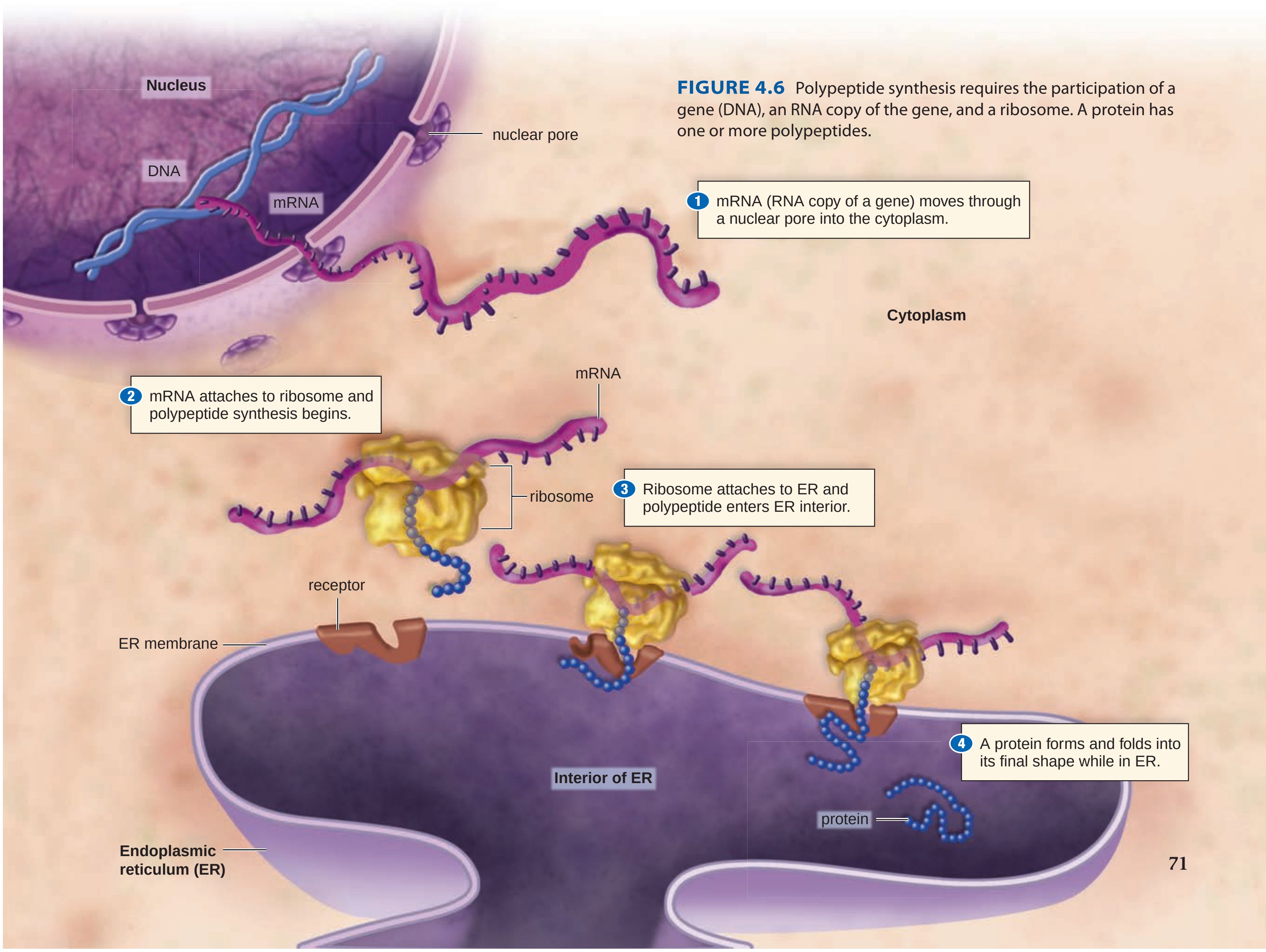

FIGURE 4.6 Polypeptide synthesis requires the participation of a gene (DNA), an RNA copy of the gene, and a ribosome. A protein has one or more polypeptides.

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4.7 The endoplasmic reticulum synthesizes and transports proteins and lipids

The term endoplasmic reticulum is a difficult one but becomes simpler if we break it down. *Endoplasmic* means "within the plasm" of the cell and *reticulum* is an elegant way of saying "network". The endoplasmic reticulum (ER) is physically continuous with the outer membrane of the nuclear envelope. It consists of membranous tubules and flattened sacs that typically account for more than half of the total membrane within an average animal cell. The membrane of the ER is continuous and encloses a single internal space. This space will be termed the interior of ER (**Fig. 4.7**). The ER twists and turns as it courses through the cytoplasm like a long snake. This structure gives the ER much more membrane than if it were simply one large sac. If you compare Figure 4.6 to Figure 4.7, you can see that Figure 4.6 shows only a small portion of the ER found in a cell.

Because many ribosomes attach themselves to the ER, it becomes the location where all the proteins are produced for the many membranes inside a eukaryotic cell as well as most of the proteins that are secreted from the cell. In humans, the protein insulin is secreted by the pancreas into the blood and then circulates about the body. Aside from proteins, the ER also produces various lipids.

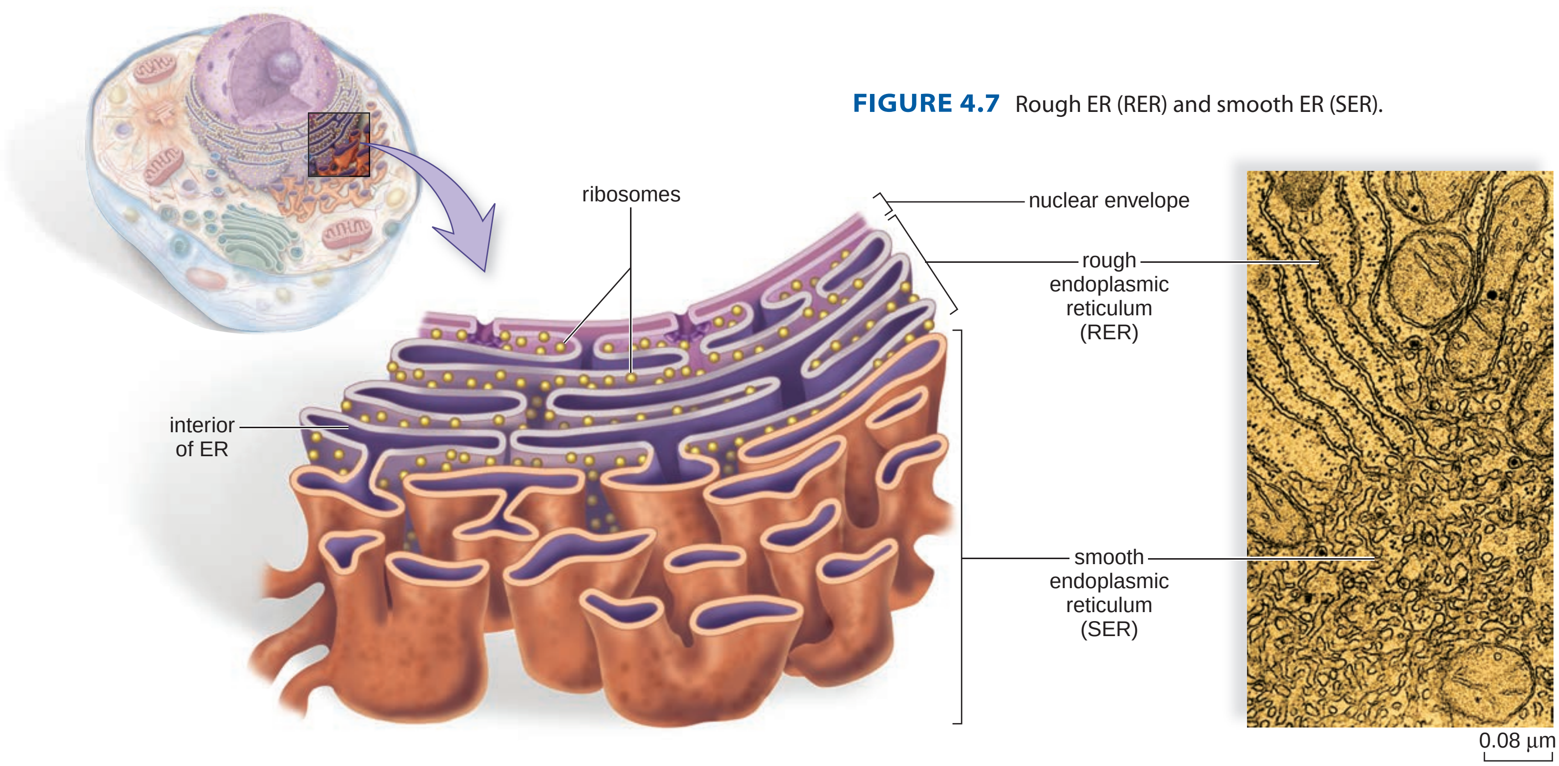
Types of ER The ER is divided into the rough ER and the smooth ER. Only the **rough ER (RER)** is studded with ribosomes. The ribosomes are attached to the side of the membrane that faces the cytoplasm. Figure 4.6 shows how a polypeptide enters the interior of the ER from an attached ribosome. Once inside, a polypeptide is usually modified before it undergoes the process of folding into the final shape of a protein. For example, carbohydrate chains are often added to certain proteins.

Smooth ER (SER), which is continuous with rough ER, does not have attached ribosomes. Therefore, it has a smooth appearance in electron micrographs and more important it does not participate in polypeptide synthesis. Smooth ER is abundant in gland cells, where it synthesizes lipids of various types. For example, cells that synthesize steroid hormones from cholesterol have much SER. The SER houses the enzymes needed to make cholesterol and modify it to produce the hormones. In the liver, SER, among other functions, adds lipid to proteins, forming the lipoproteins that carry cholesterol in the blood. Also, the SER of the liver increases in quantity when a person consumes alcohol or takes barbiturates on a regular basis, because SER contains the enzymes that detoxify these molecules.

The RER and SER, working together, produce membrane, which is composed of phospholipids and various types of proteins. Because the ER produces membrane, it can form the transport vesicles by which it communicates with the Golgi apparatus. Proteins to be secreted from the cell are kept in the interior of the ER, but the ones destined to become membrane constituents become embedded in its membrane. **Transport vesicles** pinch off from the ER and carry membranes, proteins, and lipids, notably to the Golgi apparatus, where they undergo further modification. The products of the Golgi apparatus are utilized by the cell or repackaged in secretory vesicles that make their way to the plasma membrane where they are secreted (see Fig. 4.12).

▶ **4.7 Check Your Progress** **Is it correct to say that *all* ribosomes reside in the cytoplasm? Explain.**

FIGURE 4.7 Rough ER (RER) and smooth ER (SER).



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4.8 The Golgi apparatus modifies and repackages proteins for distribution

The **Golgi apparatus** is named for Camillo Golgi, who discovered its presence in cells in 1898. The Golgi apparatus, or simply the Golgi, typically consists of a stack of three to twenty slightly curved, flattened saccules whose appearance can be compared to a stack of pancakes (**Fig. 4.8**). One side of the stack is directed toward the ER, and the other side is directed toward the plasma membrane. Vesicles can frequently be seen at the edges of the saccules.

The Golgi receives, processes, and packages proteins and lipids, so that they may be sent to their final destination in the cell. In particular, it readies proteins for secretion. Protein-filled vesicles that bud from the rough ER and lipid-filled vesicles that bud from the smooth ER are received by the Golgi at its inner face. Thereafter, the Golgi alters these substances as they move through its saccules. For example, the Golgi contains enzymes that modify the carbohydrate chains first attached to proteins in the rough ER. To take an example, one sugar can be exchanged for another sugar. In some cases, the modified carbohydrate chain serves as a signal molecule that determines the protein's final destination in the cell.

The Golgi sorts and packages proteins and lipids in vesicles that depart from the outer face. In animal cells, some of these vesicles are lysosomes, which are discussed next. Secretory vesicles proceed to the plasma membrane, where they stay until a signal molecule triggers the cell to release them. Then they become part of the membrane as they discharge their contents during **secretion.** Secretion is also called *exocytosis* because the substance exits the cytoplasm.

4.8 Check Your Progress How do proteins made by RER ribosomes become incorporated into a plasma membrane or secreted?

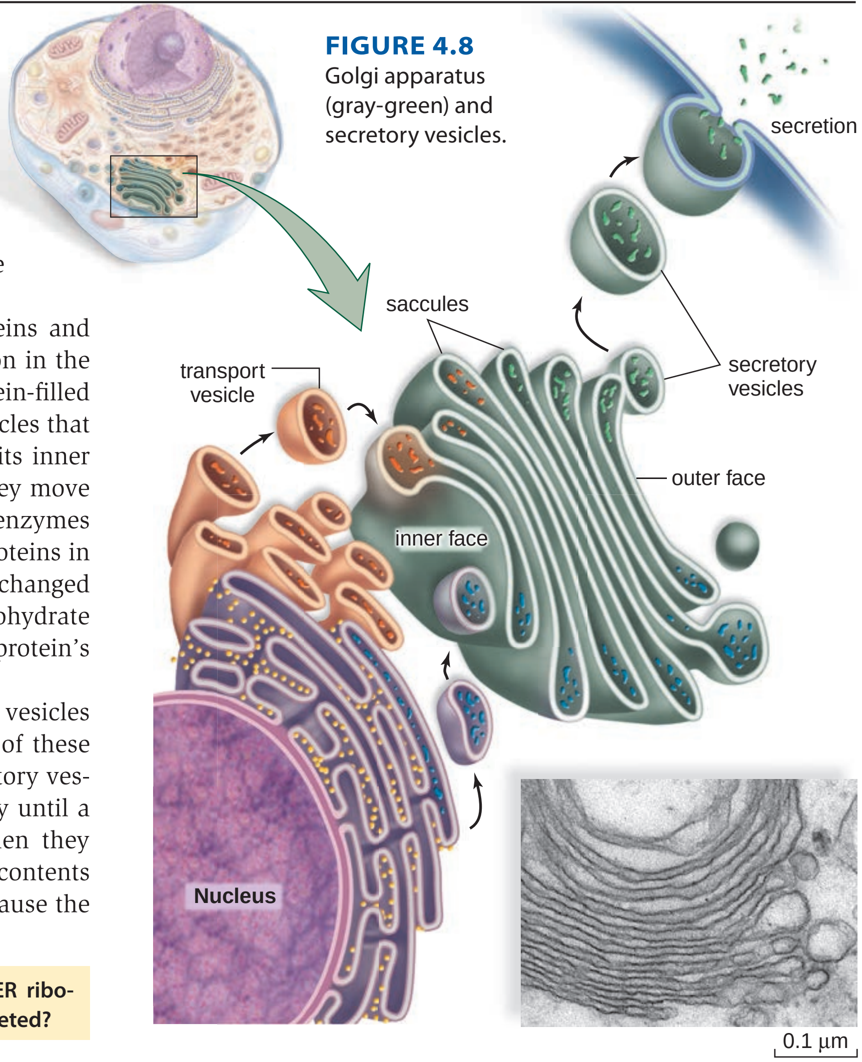

FIGURE 4.8 Golgi apparatus (gray-green) and secretory vesicles.

HOW SCIENCE PROGRESSES *Application*

4B Pulse-labeling Allows Observation of the Secretory Pathway

The pathway of protein secretion was observed by George Palade and his associates using a pulse-chase technique. The rough ER was *pulse-labeled* by letting cells metabolize for a very short time with radioactive amino acids. Then the cells were given an excess of nonradioactive amino acids. This *chased* the labeled amino acids out of the ER into transport vesicles.

Electron microscopy techniques allowed these researchers to trace the fate of the labeled amino acids, as shown in **Figure 4B:** (1) The labeled amino acids were found in the ER, then in (2) transport vesicles, and then in (3) the Golgi apparatus, before appearing in (4) vesicles at the plasma membrane and finally being released.

FORM YOUR OPINION

1. Why would Palade have labeled sulfur and not carbon in the amino acids? (See Fig. 3.9A.)
2. Where else might Palade have found the labeled amino acids in the cell? (See Fig. 4.6.)

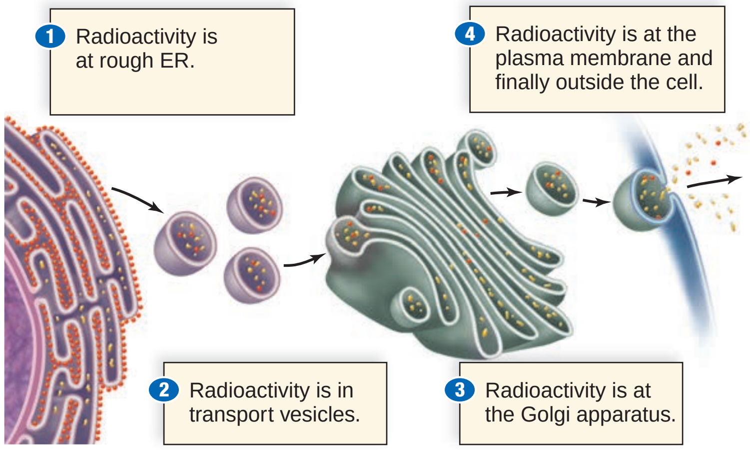

FIGURE 4B The secretory pathway.

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Vacuoles and Vesicles Have Varied Functions

Learning Outcomes

- Describe the structure and function of lysosomes and peroxisomes. (4.9, 4.10)
- Explain the varied functions of vacuoles and vesicles in protist, plant, and animal cells. (4.11–4.12)

Cells have various membranous sacs that look the same in electron micrographs but have different functions. Lysosomes contain powerful hydrolytic enzymes that digest biomolecules, even if they form cell parts. Peroxisomes are more specialized and assist mitochondria by breaking down lipids. Some of the vacuoles in protists and plants are unique to them and not found in other eukaryotes. Vesicles allow the organelles of the endomembrane system to work together.

4.9 Lysosomes digest biomolecules and cell parts

Lysosomes are vesicles produced by the Golgi apparatus. They have a very low internal pH and contain powerful hydrolytic digestive enzymes. Lysosomes are important in recycling cellular material and digesting worn-out organelles, such as old mitochondria (**Fig. 4.9**).

Sometimes biomolecules are engulfed (brought into a cell by vesicle formation) at the plasma membrane. When a lysosome fuses with such a vesicle, its contents are digested by lysosomal enzymes into simpler subunits that then enter the cytoplasm. Some white blood cells defend the body by engulfing bacteria, which are then enclosed within vesicles. When lysosomes fuse with these vesicles, the bacteria are digested.

Lysosomal storage diseases occur when a particular lysosomal enzyme is nonfunctional. Tay Sachs disease is one such condition, in which a newborn appears healthy but then gradually becomes nonresponsive, deaf, and blind before dying within a few months. The brain cells are filled with particles containing a type of lipid that cannot be digested by lysosomes.

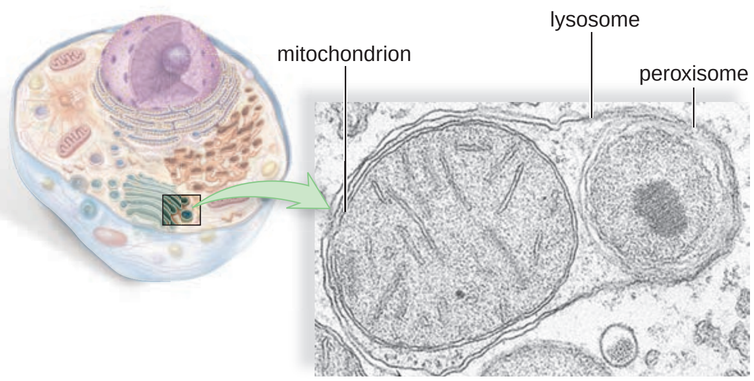

FIGURE 4.9 Lysosome fusing with and destroying spent organelles.

4.9 Check Your Progress Some white blood cells have granules, now known to be lysosomes. Why would it be beneficial for white blood cells to have lysosomes for fighting viruses and bacteria?

4.10 Peroxisomes break down long-chain fatty acids

Peroxisomes are small, membrane-bounded organelles that look very much like empty lysosomes. However, peroxisomes contain their own set of enzymes and carry out entirely different functions. Chiefly, peroxisomes bear the burden of breaking down excess quantities of long-chain fatty acids to products that can be metabolized by mitochondria for the production of ATP. In the process, they produce hydrogen peroxide (H_2O_2), a toxic molecule that is then broken down to oxygen and water.

Peroxisomes also help produce cholesterol and important phospholipids found primarily in brain and heart tissue. In germinating seeds, peroxisomes convert fatty acids and lipids to sugars. The sugars are used as a source of energy by a germinating plant. It is fair to say that peroxisomes contribute to the energy metabolism of cells.

Normally, peroxisome size and number increase or decrease according to the needs of the cell. On rare occasions, long-chain fatty acids accumulate in cells because they are unable to enter peroxisomes for breakdown due to an inherited disorder. This leads to dramatic deterioration of the nervous system. The 1992 movie *Lorenzo's Oil* told the true story of a boy who had this condition.

4.10 Check Your Progress Why would you expect to find peroxisomes in the vicinity of mitochondria?

4.11 Vacuoles are common to plant cells

Like vesicles, **vacuoles** are membranous sacs, but vacuoles are larger than vesicles. The vacuoles of some protists are quite specialized; they include contractile vacuoles for ridding the cell of excess water and digestive vacuoles for breaking down nutrients.

Vacuoles usually store substances. Plant vacuoles contain not only water, sugars, and salts, but also water-soluble pigments and toxic molecules. The pigments are responsible for the red, blue, or purple colors of many flowers and some leaves. The toxic substances help protect a plant from herbivorous animals.

Typically, plant cells have a large **central vacuole** that may occupy up to 90% of the volume of the cell (**Fig. 4.11**). This vacuole is filled with a watery fluid called cell sap and it gives added support to cells and in that way helps a plant stay upright, since plants don't have a bony skeleton as many animals do.

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The central vacuole stores needed substances and also waste products. A system to excrete wastes never evolved in plants, most likely because their metabolism is incredibly efficient and they produce little metabolic waste. What wastes they do produce are pumped into the central vacuole and stored there permanently. As organelles age and become nonfunctional, they fuse with the vacuole, where digestive enzymes break them down. This function is carried out by lysosomes in animal cells.

4.11 Check Your Progress **How is the central vacuole of plant cells similar to but different from the lysosomes of animal cells?**

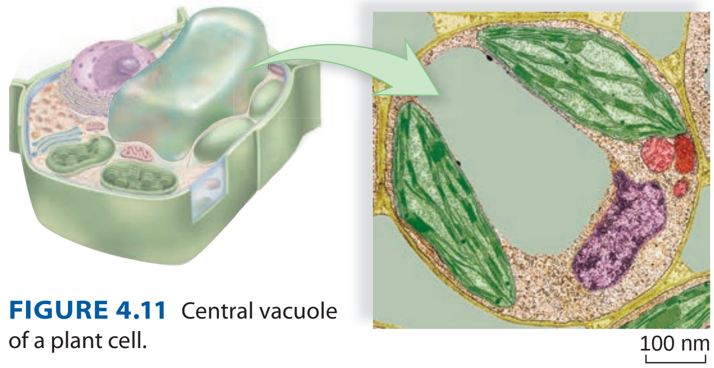


FIGURE 4.11 Central vacuole of a plant cell.

4.12 Vesicles allow the organelles of the endomembrane system to work together

The **endomembrane system** includes various membranous organelles that work together and communicate by means of transport vesicles. It includes the endoplasmic reticulum (ER), the Golgi apparatus, lysosomes, and the transport vesicles.

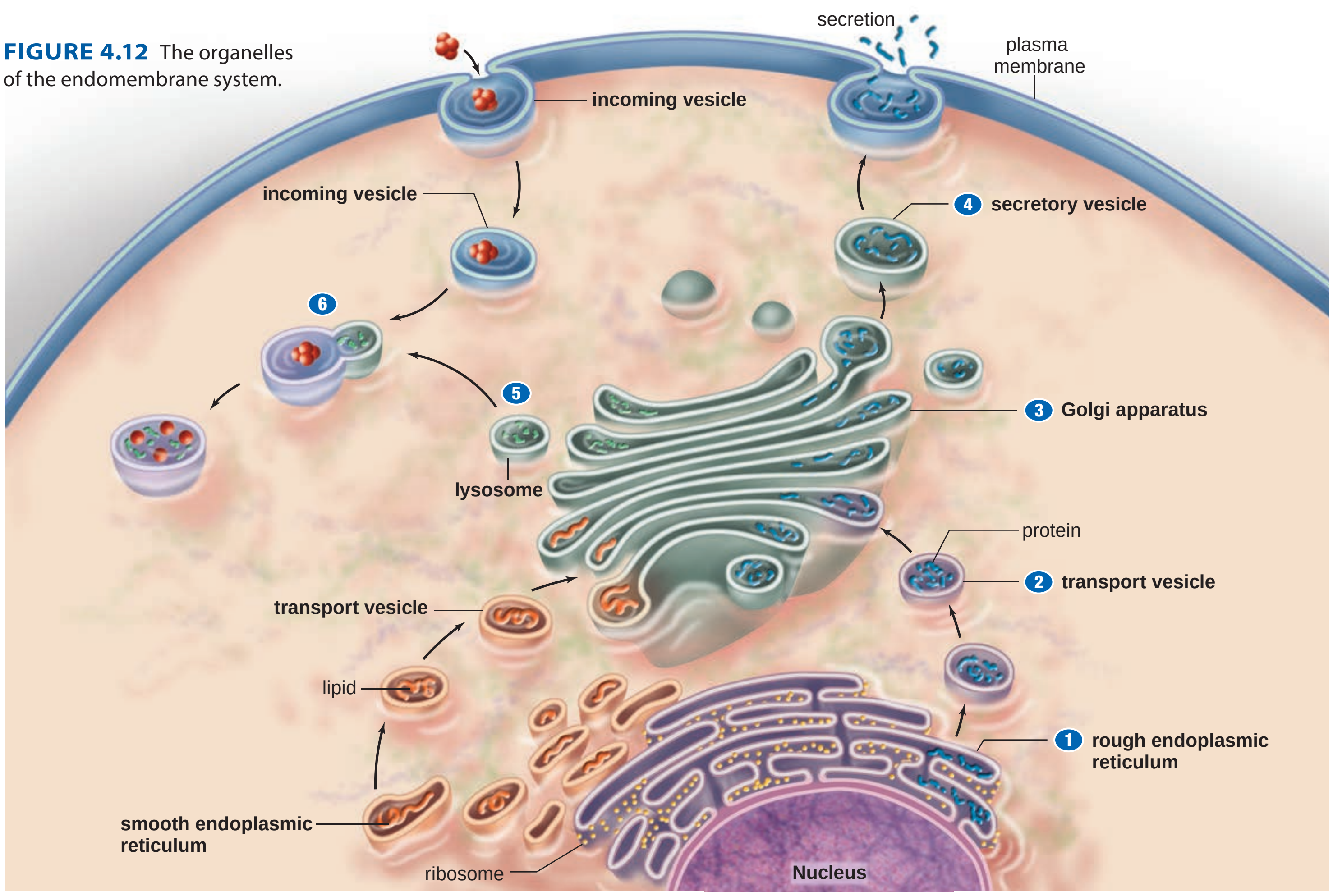
Figure 4.12 shows how the components of the endomembrane system work together: **1** Proteins, produced in the rough ER, are carried in **2** transport vesicles to **3** the Golgi apparatus, which sorts the proteins and packages them into vesicles that transport them to various cellular destinations.

4 Secretory vesicles take the proteins to the plasma membrane, where they exit the cell when the vesicles fuse with the membrane. This is called secretion by exocytosis. For example, secretion into ducts occurs when the salivary glands produce saliva or when the pancreas produces digestive enzymes. Similarly, lipids move from the smooth ER to the Golgi apparatus and can eventually be secreted.

5 In animal cells, lysosomes produced by the Golgi apparatus **6** fuse with incoming vesicles from the plasma membrane and digest biomolecules and debris. White blood cells are well-known for engulfing pathogens (e.g., disease-causing viruses and bacteria) that are then broken down in lysosomes.

4.12 Check Your Progress **What parts of the cell are responsible for producing and exporting the proteins found in the endomembrane system?**

FIGURE 4.12 The organelles of the endomembrane system.



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A Cell Carries Out Energy Transformations

Learning Outcome

▶ Compare and contrast the structure and function of chloroplasts and mitochondria. (4.13)

Chloroplasts transform solar energy into the energy of carbohydrates, which serve as organic food for themselves and all organisms in the biosphere. Mitochondria transform the energy of carbohydrates to that of ATP molecules. All cells use ATP molecules as a source of energy for metabolic reactions and processes.

4.13 Chloroplasts and mitochondria have opposite functions

We learned in Chapter 1 that all organisms must acquire energy and nutrients from their environment. Plants, however, can use solar energy and the inorganic nutrients water and carbon dioxide to make energy-rich carbohydrates during a process called photosynthesis. Carbohydrates serve as organic food for plants; therefore, we say that plants make their own food. Photosynthesis not only takes in carbon dioxide but also releases oxygen.

Plants can photosynthesize because their cells contain organelles called **chloroplasts.** Each plant cell may contain as many as 100 chloroplasts, and a square millimeter of leaf can contain up to 500,000 chloroplasts (**Fig. 4.13**). The green pigment chlorophyll as well as other pigments are responsible for the ability of chloroplasts to absorb solar energy. Within a chloroplast, chlorophyll is located in the membrane of flattened sacs called thylakoids.

Chloroplasts are of great significance to the biosphere, including humans, because they are the ultimate source of all food for living things. Consider that you either feed directly on plants or on animals that have fed on plants. Another source of food for the biosphere is carbohydrates made by cyanobacteria and algae, because they also use pigments to absorb solar energy and photosynthesize in the same manner as plants.

How would you know that chloroplasts produce carbohydrates when the sun is shining? One way is to look for starch grains to accumulate in plant cells when the sun is out. Set a plant in the dark and the starch grains disappear.

In contrast to chloroplasts, nearly all organisms and types of cells, including both plant and animal cells, contain mitochondria (Fig. 4.13). **Mitochondria** are indispensable to cells because they carry on cellular respiration, the process that transforms the energy of carbohydrates to that of ATP molecules. It's called cellular respiration because mitochondria take in oxygen and give off carbon dioxide. Because mitochondria produce ATP, they are called the powerhouse of a cell.

Cellular respiration and photosynthesis are opposite reactions:

$$\text{carbohydrate} + \text{oxygen} \rightleftarrows \text{carbon dioxide} + \text{water} + \text{energy}$$

For cellular respiration, read left to right and replace energy with ATP. For photosynthesis, read right to left and replace energy with solar energy.

Cells use ATP, not glucose, as a direct source of metabolic energy—using a molecule of glucose would be energy-inefficient and wasteful. You use change, not a dollar bill, to buy something

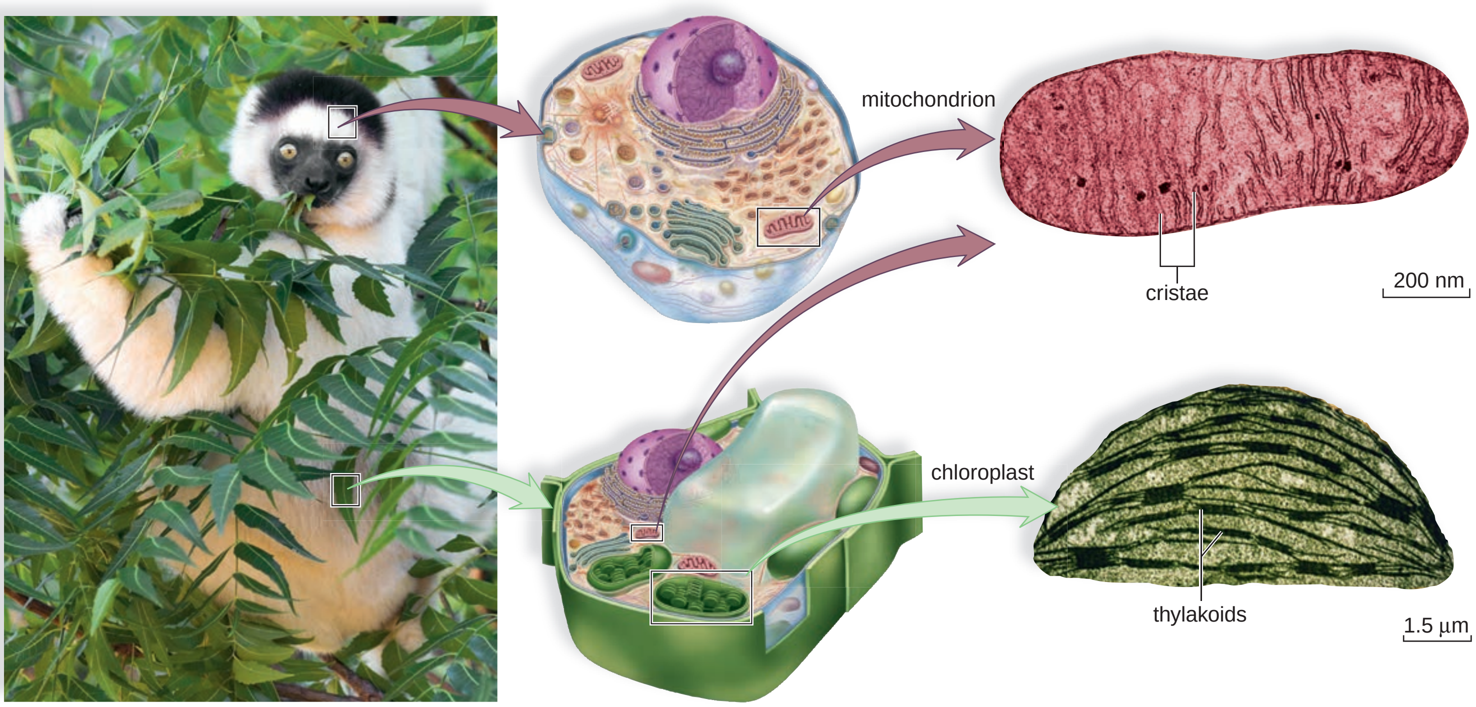

FIGURE 4.13 Plant cells carry on photosynthesis in green leaves where chloroplasts absorb solar energy because they contain the green pigment chlorophyll in thylakoid membranes. Mitochondria in plant and animal cells carry on cellular respiration, a process that produces ATP on the membranous invaginations called cristae.

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that costs five cents. In the same manner, an organism converts carbohydrates to many molecules of ATP and uses them as a source of energy for individual reactions, such as linking amino acids during protein synthesis. Mitochondria are most abundant in human cells that carry out energy-intensive activities. For example, ATP provides the energy for muscle contraction and nerve conduction. Mitochondria are not as complex as chloroplasts but their inner membrane does fold back and forth, forming the cristae that act as shelves where ATP is formed. ATP exits mitochondria and enters the cytoplasm where it is utilized as an immediate energy source.

It is of great interest to scientists that both chloroplasts and mitochondria provide evidence that they were once free-living prokaryotes. For example, they have their own DNA in a nucleoid region, and they make some of their own proteins. For a more thorough discussion of this topic, see How Life Changes on this page.

▶ **4.13 Check Your Progress** **In what ways are chloroplasts and mitochondria opposite, and in what ways are they similar?**

HOW LIFE CHANGES *Application*

4C How the Eukaryotic Cell Evolved

Life's history is written in the fossil record, which includes the remains of past life, often encased by stone (see Fig. 14A.2). The fossil record tells us that the prokaryotic cell was present about 3.5 BYA (billion years ago); the eukaryotic cell evolved in stages (**Fig. 4C**). The nuclear envelope and nucleus may have arisen around 2 BYA from an infolding of the plasma membrane, but what about the organelles such as mitochondria and chloroplasts? Much evidence supports the proposal that these organelles were once free-living prokaryotes that were either prey to or parasites of a eukaryotic cell. Their outer double membrane tells us that the eukaryotic cell engulfed them—the outer membrane is derived from the host plasma membrane, and the inner membrane was their own outer surface. By now, they are endosymbionts—organisms that live inside a host cell and are indispensable to their host, the cell that engulfed them.

Mitochondria and chloroplasts have their own DNA—circular like that of a prokaryote—and they carry on protein synthesis in the same manner as bacteria. Interestingly, chemicals that can poison and stop the metabolism in mitochondria and chloroplasts have no effect on cytoplasmic metabolism, and chemicals that poison cytoplasmic enzymes have no effect on these organelles. Then, too, they reproduce by splitting as do bacteria, and their reproduction occurs independently of host cell reproduction.

The theory of endosymbiosis explains that since all cells have mitochondria, aerobic bacteria entered the host cell first, perhaps just when oxygen began to rise in the atmosphere due to the advent of photosynthesis by free-living cyanobacteria (see page 324). A host cell with an endosymbiont that used oxygen and produced ATP molecules would have been a distinct evolutionary advantage. Later, a cyanobacterium entered certain cells, and these cells became capable of photosynthesis. Being able to make your own food does away with the need to find it elsewhere. Eventually the relationship between host cells and endosymbionts became so beneficial that by now they cannot live separately from one another!

FORM YOUR OPINION

1. Explain the phraseology "the host had an evolutionary advantage." Be sure to mention comparative number of offspring in your explanation.
2. If you compared the structure of a cyanobacterium with that of a chloroplast, what similarities would you expect to find?

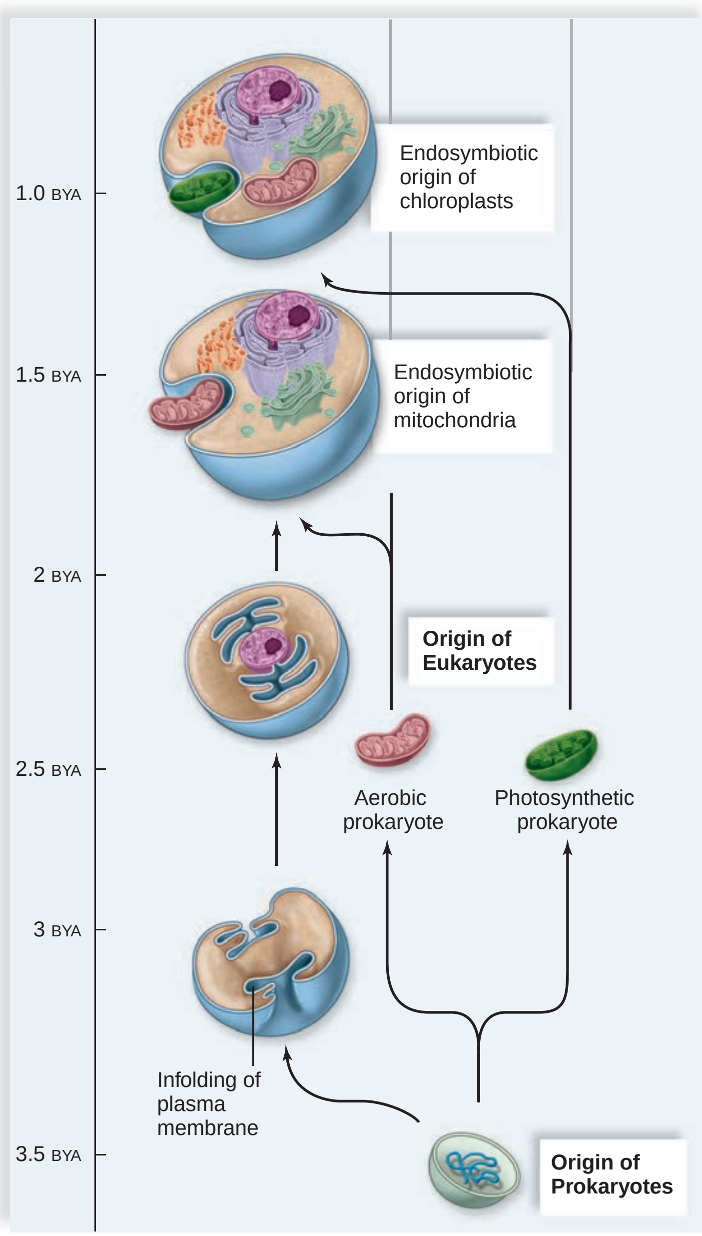

FIGURE 4C The eukaryotic cell was fully formed when a nucleated cell engulfed prokaryotes that became endosymbionts.

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The Cytoskeleton Is Dynamic

Learning Outcomes

- Discuss the function and composition of the cytoskeleton. (4.14)
- Compare and contrast the structure and function of fibers making up the cytoskeleton. (4.14)
- Explain the structure of cilia and flagella, and give examples of their importance to the body. (4.15)

As you know, bones and muscles give an animal structure and produce movement. Similarly, the fibers of the cytoskeleton maintain cell shape and cause the cell and its organelles to move. Cilia and flagella are also instrumental in producing movement, so they are included in this part of the chapter as well.

4.14 The cytoskeleton maintains cell shape and assists movement

All eukaryotic cells have a **cytoskeleton,** a network of protein fibers within the cytoplasm. Even though both plant and animal cells have a cytoskeleton, most of our discussion pertains to an animal cell. The cytoskeleton supports the animal cell and determines its shape. Remarkably, however, the protein fibers of the cytoskeleton can assemble and disassemble rapidly, and this accounts for why the shape of some animal cells can change from moment to moment. Similarly, the cytoskeleton anchors the organelles in place but can also allow them to move, as when a vesicle moves from the Golgi to the plasma membrane. Because the cytoskeleton has the dual function of support and movement, it is appropriately described as the "skeleton and muscles" of an animal cell.

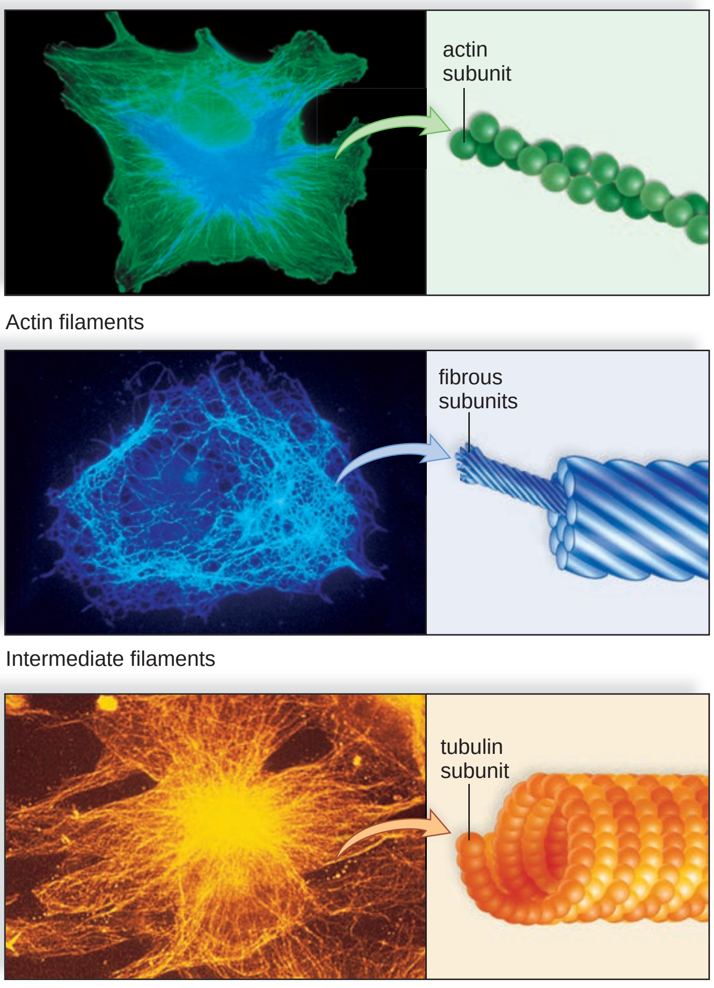
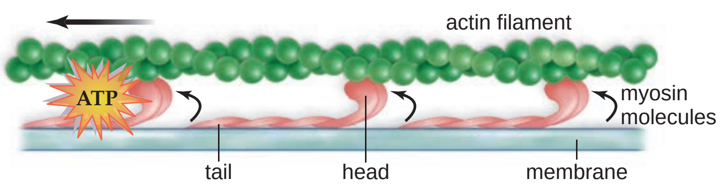


FIGURE 4.14A The cytoskeleton contains these three types of fibers that support the cell.

If you could look closely at the cytoskeleton in an animal cell, you would note three types of fibers: actin filaments, intermediate filaments, and microtubules. Because you can't see these fibers with a light microscope, scientists prepare fluorescent antibodies, each of which attaches to only one type of fiber and then they photograph the cells under fluorescent light (**Fig. 4.14A**).

Much has been learned about the structure and function of each component of the cytoskeleton. The **actin filaments** are so named because they contain two twisted strands of actin, a fibrous protein. Bundles of actin filaments support the plasma membrane and other structures, such as the microvilli (short projections) of intestinal cells. However, you can primarily associate actin filaments with movement. For example, actin interacts with another protein, myosin, when muscle contraction occurs. Myosin is a motor molecule that functions just as you do when participating in a tug of war: Myosin heads attach, detach, and reattach further along the actin filament, and this pulls the actin filament along:



Also in conjunction with myosin, actin acts like purse strings to pinch off and separate cells during cell division. On the other hand, actin is working alone when white blood cells crawl along and their projections (called pseudopods) engulf disease-causing agents such as viruses and bacteria.

Intermediate filaments are intermediate in size between actin filaments and microtubules. Although the specific protein composition varies with the type of cell, intermediate filaments always have a ropelike structure that provides mechanical strength. Some intermediate filaments support the nuclear envelope, whereas others support the plasma membrane and take part in the formation of cell-to-cell junctions. Intermediate filaments made of the protein keratin strengthen skin cells.

Microtubules, as their name implies, are short, cylindrical structures composed of 13 rows of a protein called tubulin. Assembly is under the control of a microtubule organizing center (MTOC) located in the **centrosome** (see Fig. 4.4A). Microtubules radiate from the centrosome, helping to maintain the shape of

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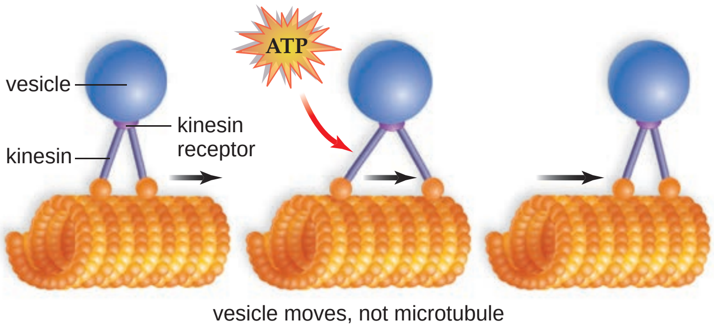


FIGURE 4.14B The motor molecule kinesin is moving a vesicle along a microtubule track.

the cell and acting as tracks along which organelles can move (**Fig. 4.14B**). The motor molecules kinesin and dynein are associated with microtubules.

Before a cell divides, microtubules disassemble and then reassemble into a structure called a spindle, which distributes chromosomes in an orderly manner. Plants have evolved various types of poisons that help prevent them from being eaten by herbivores. One of these, called colchicine, is a chemical that binds to tubulin and blocks the assembly of microtubules so that cell division is impossible.

▶ **4.14 Check Your Progress** **A cell is dynamic. In general, what accounts for the ability of cell contents to move?**

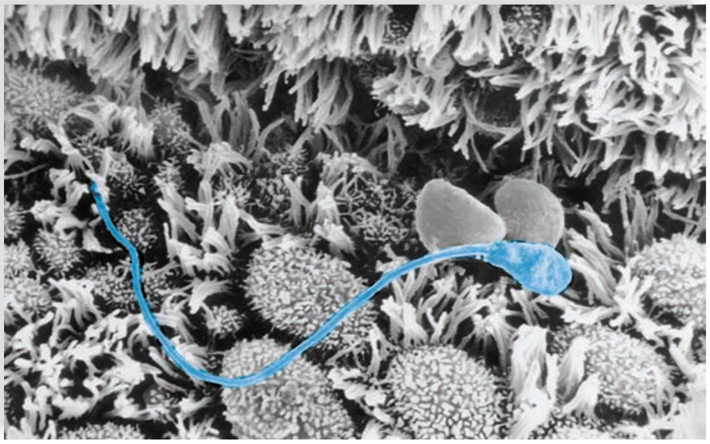
4.15 Cilia and flagella permit movement

Cilia and flagella (sing., cilium, flagellum) are whiplike projections of cells. **Cilia** move stiffly, like an oar, and **flagella** move in an undulating, snakelike fashion. Cilia are short (2–10 μm), and flagella are longer (usually no more than 200 μm). Unicellular protists utilize cilia or flagella to move about. In our bodies, ciliated cells are critical to respiratory health and our ability to reproduce. The ciliated cells that line our respiratory tract sweep debris trapped within mucus back up into the throat, which helps keep the lungs clean. Similarly, ciliated cells move an egg along the oviduct, where it can be fertilized by a flagellated sperm cell.

A cilium and a flagellum have the same organization of microtubules within a plasma membrane covering (**Fig. 4.15,** *right*). Attached motor molecules, powered by ATP, allow the microtubules in cilia and flagella to interact and bend, and thereby to move.

A particular genetic disorder illustrates the importance of normal cilia and flagella (**Fig. 4.15,** *left*). Some individuals have an inherited defect that leads to malformed microtubules in cilia and flagella. Not surprisingly, they suffer from recurrent and severe respiratory infections, because the ciliated cells lining their respiratory passages fail to keep their lungs clean. They are also infertile due to the lack of ciliary action to move the egg in a female, or the lack of flagellar action by sperm in a male.

FIGURE 4.15 (*right*) The presence of microtubules and motor molecules (dynein) allows a flagellum to move. (*left*) Micrograph of cilia and flagella.

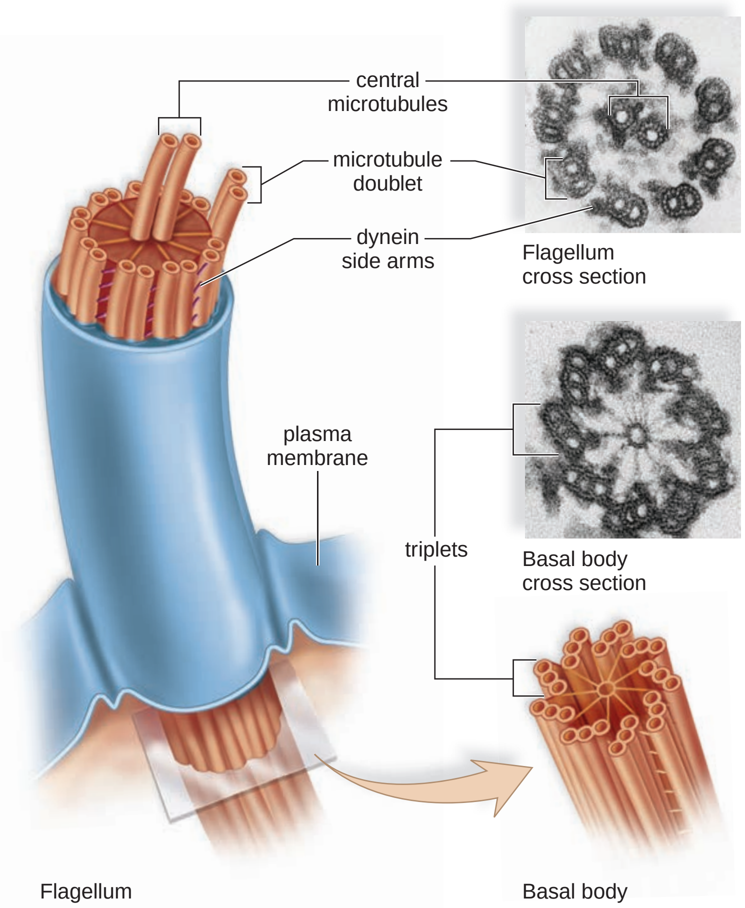


Flagellated sperm in oviduct lined by ciliated cells

Centrioles Located in the centrosome, **centrioles** are short, barrel-shaped organelles composed of microtubules. It's possible that centrioles give rise to **basal bodies,** which lie at the base of and are believed to organize the microtubules in cilia and flagella. It's also possible that centrioles help organize the spindle, mentioned earlier, which is so necessary to cell division.

We have completed our study of eukaryotic organelles. In the next part of the chapter, we review how cell structures work together.

▶ **4.15 Check Your Progress** **How do cilia and flagella differ in structure and movement?**



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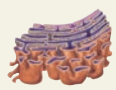
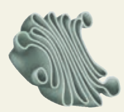
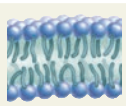
Cell Structures Work Together

Learning Outcome

- Discuss the function of cell parts according to four categories: protein synthesis and modification; storage, transport, and digestion; energy transformations; and cell shape and movement.

Cell structures can be grouped into four categories according to their functions. Understanding how these structures function together for the benefit of the cell facilitates learning them.

TABLE 4.16 Eukaryotic Cell Structures

Function	Cell Structure	Description	Function
Protein Synthesis and Modification	Nucleus 	Bounded by nuclear envelope with pores; contains DNA within chromosomes and nucleolus	Acts as control center of cell; specifies protein synthesis
	Ribosomes 	Small particles, each with two subunits	Are sites of protein synthesis
	Endoplasmic reticulum (ER) 	Network of membranous tubules and flattened sacs Rough ER: studded with ribosomes Smooth ER: lacks ribosomes	 Carries out protein synthesis and modification; forms transport vesicles Carries out lipid synthesis; forms transport vesicles
	Golgi apparatus 	Stack of flattened saccules	Carries out processing and packaging of proteins and lipids; forms secretory vesicles
Storage, Transport, and Digestion	Vesicle 	Tiny membranous sac	Stores and transports proteins and lipids
	Vacuole 	Small to large membranous sac	In plants, a large vacuole stores substances including wastes
	Lysosome 	A type of vesicle	Digests biomolecules and cell parts
	Peroxisome 	A type of vesicle	Assists with lipid metabolism, breakdown of poisons
Energy Transformations	Chloroplast 	Bounded by a double membrane	Carries on photosynthesis and produces carbohydrate
	Mitochondrion 	Bounded by a double membrane; inner membrane forms cristae	Carries on cellular respiration and produces ATP molecules
Cell Shape and Movement	Plasma membrane 	Phospholipid bilayer with embedded proteins	Regulates entrance and exit of molecules into and out of cell
	Cell wall	In plant cells, outer layer of cellulose	Helps maintain shape of cell, protects and supports
	Cytoskeleton	Network of protein fibers	Supports organelles, assists movement of cell and its parts
	Flagella and cilia	Microtubule-containing cellular extensions	Move the cell or move substances along its surface

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THE CHAPTER IN REVIEW

SUMMARY

Cells Are the Basic Units of Life

4.1 All organisms are composed of cells

- The **cell theory** states the following:
  - A cell is the basic unit of life.
  - All living things are made up of cells.
  - New cells arise only from preexisting cells.

4.2 Metabolically active cells are small in size

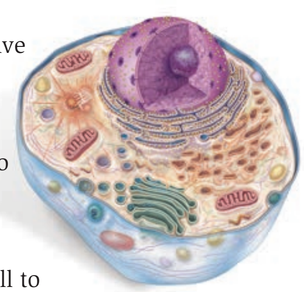
- Cells must remain small in order to have an adequate **surface-area-to-volume ratio.**

4.3 Prokaryotic cells evolved first

- **Prokaryotic cells** have the following characteristics:
  - Lack a membrane-bounded nucleus; the chromosome is in a region called the **nucleoid.**
  - Have a **plasma membrane** surrounding the **cytoplasm** (semifluid interior contains **ribosomes**), which in turn is bounded by a **cell wall** and a **capsule. Pili** allow the cell to attach to solid substances.
  - Are simpler and much smaller than eukaryotic cells.
  - Are members of domains **Archaea** and **Bacteria.**

4.4 Eukaryotic cells contain specialized organelles: An overview

- Organisms in the domain **Eukarya,** have **eukaryotic cells** with the following characteristics:
  - A membrane-bounded **nucleus.**
  - **Organelles,** structures specialized to perform specific functions.
  - Compartmentalization through the presence of membranous organelles, allowing a eukaryotic cell to be larger than a prokaryotic cell.



Protein Synthesis Is a Major Function of Cells

4.5 The nucleus contains the cell's genetic information

- Genes, composed of DNA, are located within **chromatin** that become organized as **chromosomes** when nuclear division occurs.
- **Nuclear pores** in the **nuclear envelope** permit communication between the nucleus and the cytoplasm.
- The **nucleolus** produces ribosomal subunits.

4.6 The ribosomes carry out protein synthesis

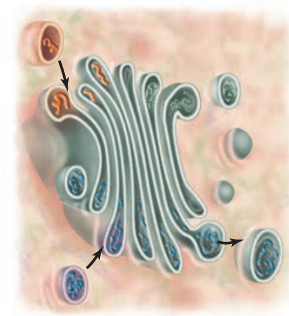
- Ribosomes in the cytoplasm and on the **endoplasmic reticulum (ER)** synthesize proteins.
- The proteins synthesized at the ribosomes enter the interior of the ER where the protein takes on its final shape.

4.7 The endoplasmic reticulum synthesizes and transports proteins and lipids

- The ER produces proteins **(rough ER)** and lipids **(smooth ER)** that become incorporated in membrane or are secreted from the cell.
- **Transport vesicles** from the ER carry proteins and lipids to the Golgi apparatus.

4.8 The Golgi apparatus modifies and repackages proteins for distribution

- Enzymes modify carbohydrate chains attached to proteins.
- Vesicles leave the **Golgi apparatus** and travel to the plasma membrane, where **secretion** occurs.



Vacuoles and Vesicles Have Varied Functions

4.9 Lysosomes digest biomolecules and cell parts

- **Lysosomes,** which are vesicles produced by the Golgi apparatus, contain hydrolytic digestive enzymes.

4.10 Peroxisomes break down long-chain fatty acids

- **Peroxisomes,** which are vesicles resembling lysosomes, break down long-chain fatty acids.

4.11 Vacuoles are common to plant cells

- **Vacuoles,** like vesicles, are membranous sacs.
- Vacuoles are larger than vesicles and usually store substances.
- Plant cells have a large **central vacuole** that stores watery cell sap and maintains turgor pressure.

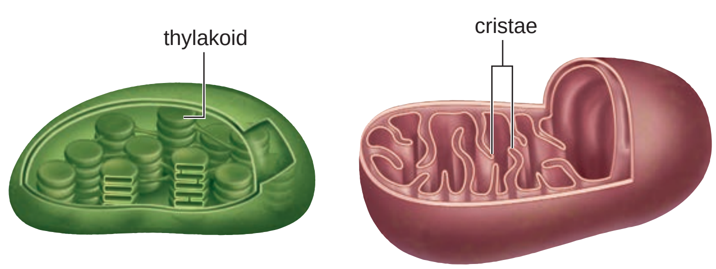
4.12 Vesicles allow the organelles of the endomembrane system to work together

- The ER, Golgi apparatus, lysosomes, and transport vesicles make up the **endomembrane system.**

A Cell Carries Out Energy Transformations

4.13 Chloroplasts and mitochondria have opposite functions

- **Chloroplasts** carry on photosynthesis and produce carbohydrates.
- In chloroplasts, thylakoids (containing chlorophyll) capture solar energy.
- **Mitochondria** carry on cellular respiration and break down carbohydrates.
- In mitochondria, the cristae produce ATP, and therefore they are the power house of the cell.



The Cytoskeleton Is Dynamic

4.14 The cytoskeleton maintains cell shape and assists movement

- **Actin filaments** are organized in bundles or networks.
- **Intermediate filaments** are ropelike assemblies of polypeptides.
- **Microtubules** are made of the globular protein tubulin. They act as tracks for organelle movement.

- The microtubule organizing center (MTOC) regulates microtubule assembly and is located in the **centrosome.**

4.15 Cilia and flagella permit movement

- **Cilia** (short) and **flagella** (long) are projections from the cell that allow the cell to move.
- Cilia and flagella grow from **basal bodies,** perhaps derived from **centrioles.**

Cell Structures Work Together

- See Table 4.16.

TESTING YOURSELF

Cells Are the Basic Units of Life

1. The cell theory states
   a. cells form as organelles and molecules become grouped together in an organized manner.
   b. the normal functioning of an organism depends on its individual cells.
   c. the cell is the basic unit of life.
   d. only eukaryotic organisms are made of cells.
2. When you examine a cell using a light microscope, which might you be able to see?
   a. the nucleus only
   b. the nucleus and the nucleolus
   c. the nucleus, the nucleolus, and the threads of chromatin
   d. all of these plus the DNA double helix
3. The small size of cells best correlates with
   a. their ability to reproduce.
   b. their prokaryotic versus eukaryotic nature.
   c. an adequate surface area for exchange of materials.
   d. their vast versatility.
   e. All of these are correct.
4. Which size relationship is incorrect?
   a. The Golgi apparatus is smaller than a mitochondrion.
   b. The nucleus is smaller than a chloroplast.
   c. The entire endoplasmic reticulum is larger than the cell.
   d. The area of the plasma membrane is larger than that of the cytoskeleton.
   e. All of these are incorrect.
5. Which of the following structures are found in both plant and animal cells?
   a. centrioles
   b. chloroplasts
   c. cell wall
   d. mitochondria
   e. All of these are found in both types of cells.
6. Eukaryotic cells compensate for a low surface-to-volume ratio by
   a. taking up materials from the environment more efficiently.
   b. lowering their rate of metabolism.
   c. compartmentalizing their activities into organelles.
   d. reducing the number of activities in each cell.
7. The cell wall and capsule of bacteria
   a. are located inside the plasma membrane.
   b. compensate for the lack of a plasma membrane.
   c. provide easy access to the cytoplasm.
   d. have projections called pili.
   e. Both b and c are correct.
8. **THINKING CONCEPTUALLY** What evidence would best convince you that bacteria are on your skin?

Protein Synthesis Is a Major Function of Cells

9. What is synthesized by the nucleolus?
   a. mitochondria c. transfer RNA
   b. ribosomal subunits d. DNA
10. Ribosomes are found
   a. at the Golgi apparatus.
   b. in the cytoplasm and on the rough endoplasmic reticulum.
   c. in the nucleus and nucleolus.
   d. at the plasma membrane releasing proteins.
   e. All of these are correct.
11. The organelle that can modify a protein and determine its destination in the cell is the
   a. ribosome. c. Golgi apparatus.
   b. vacuole. d. lysosome.
12. Which of these is not involved in protein synthesis and secretion?
   a. smooth ER c. plasma membrane
   b. nucleus d. All of these are correct.
13. **THINKING CONCEPTUALLY** Communication is critical in cells. How does the nucleus communicate with the cytoplasm, and how does the rough ER communicate with the Golgi?

Vacuoles and Vesicles Have Varied Functions

14. The central vacuole of plant cells may contain
   a. flower color pigments.
   b. toxins that protect plants against herbivorous animals.
   c. sugars.
   d. All of these are correct.
15. __________ are produced by the Golgi apparatus and contain __________.
   a. Lysosomes, DNA
   b. Mitochondria, DNA
   c. Lysosomes, enzymes
   d. Nuclei, DNA
16. Vesicles from the ER most likely are on their way to
   a. the rough ER.
   b. the lysosomes.
   c. the Golgi apparatus.
   d. the plant cell vacuole only.
   e. the location suitable to their size.
17. Which organelle in the endomembrane system is incorrectly matched with its function?
   a. Nucleus—contains genetic information regarding the sequence of amino acids in proteins
   b. Transport vesicles—the way the nucleus communicates with the ER
   c. Golgi apparatus—involved in modification and packaging of proteins
   d. Lysosomes—digest biomolecules and cell parts
   e. All of these associations are correct.
18. **THINKING CONCEPTUALLY** A concept is an encompassing idea tested by the scientific method. The concept of the endomembrane system is based on what data?

A Cell Carries Out Energy Transformations

19. Mitochondria
   a. are involved in cellular respiration.
   b. break down ATP to release energy for cells.
   c. contain stacks of thylakoid membranes.
   d. are present in animal cells but not in plant cells.
   e. All of these are correct.

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20. The products of photosynthesis are
   a. glucose and oxygen.
   b. oxygen and water.
   c. carbon dioxide and water.
   d. glucose and water.
21. Why are mitochondria but not chloroplasts called the powerhouses of the cell?
   a. Mitochondria form glucose, but chloroplasts break it down.
   b. Mitochondria but not chloroplasts have their own genetic material.
   c. Mitochondria but not chloroplasts capture solar energy.
   d. Mitochondria but not chloroplasts directly provide ATP to the cell.
   e. Both a and b are correct.
22. **THINKING CONCEPTUALLY** Both chloroplasts and mitochondria are critical to your existence. How so?

The Cytoskeleton Is Dynamic

23. Which of these are involved in movement of the cell or the cell contents?
   a. actin filaments
   b. microtubules
   c. basal bodies
   d. All of these are correct.
24. Which of these statements is not true?
   a. Actin filaments are found in muscle cells.
   b. Microtubules radiate from the ER.
   c. Intermediate filaments sometimes contain keratin.
   d. Motor molecules that are moving organelles use microtubules as tracks.
25. Plant cells lack centrioles, and this correlates with their lack of
   a. mitochondria.
   b. flagella.
   c. a large central vacuole.
   d. All of these are correct

Cell Structures Work Together

For questions 26–30, match the functions to the organelles in the key.

KEY:
   a. endoplasmic reticulum and Golgi apparatus
   b. peroxisomes and lysosomes
   c. chloroplast and mitochondria
   d. centrosome and microtubules
   e. nucleus and ribosomes

26. Carbohydrate metabolism resulting in ATP formation
27. Contain enzymes for breaking down substances
28. Protein formation and secretion
29. Protein production as DNA dictates
30. Movement of the cell and its parts

THINKING SCIENTIFICALLY

1. Utilizing Palade's procedure, described on page 73, you decide to label and trace the base uracil. What type of molecule are you labeling, and where do you expect to find it in Figure 4B?
2. After publishing your study from question 1, you are criticized for failing to trace uracil from mitochondria. Why might you have looked for uracil in mitochondria, and what comparative difference between the nuclear envelope and the mitochondrial double membrane might justify your study as is?

ONLINE RESOURCE

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Enhance your study with animations that bring concepts to life and practice tests to assess your understanding. Your instructor may also recommend the interactive eBook, individualized learning tools, and more.

CONNECTING THE CONCEPTS

Our knowledge of cell anatomy has been gathered by studying micrographs of cells. This has allowed cytologists (biologists who study cells) to arrive at a generalized picture of cells, such as those depicted for an animal and a plant cell in Section 4.4. Eukaryotic cells, taken as a whole, contain several types of organelles, and the learning outcomes for the chapter suggest that you should know the structure and function of each one. A concept to keep in mind is that "structure suits function." For example, ribosomal subunits move from the nucleus to the cytoplasm; therefore, it seems reasonable that the nuclear envelope has pores. Finding relationships between structure and function will give you a deeper understanding of the cell and boost your memory capabilities.

Also, realizing that the organelles work together is helpful. If you wanted to describe the involvement of cell parts to make a protein, you would start with the nucleus because chromosomes contain DNA, which specifies the order of amino acids in a particular protein. From there, you would mention the ribosomes at the rough endoplasmic reticulum (RER), transport vesicles, the Golgi apparatus, and a possible final destination for the protein. Analogies can help. For example, the endomembrane system can be compared to a post office: Proteins (the letters) are deposited into the RER (the local post office), which sends them to a Golgi (the regional sorting center) from which they are sent to their correct destinations. The pulse-labeling technique, described in Section 4B, provides evidence to support this analogy.

Table 4.16 shows you other ways to group the organelles. Lysosomes and peroxisomes are vesicles with digestive functions: Lysosomes digest various biomolecules while peroxisomes break down lipids.

The origin of the eukaryotic cell links together what you know about the structure of prokaryotic and eukaryotic cells because the endosymbiotic theory says that mitochondria and chloroplasts were once free-living prokaryotes.

In Chapter 5, we continue our general study of the cell by considering some of the functions common to all cells. For example, all cells exchange substances across the plasma membrane, and they also carry out enzymatic metabolic reactions, which either release or require energy.

PUT THE PIECES TOGETHER

1. Use the structure of the prokaryotic cell to support the endosymbiotic theory.
2. Explain how the structure of the endoplasmic reticulum suits its function.
3. Microtubules are a part of the cytoskeleton and are found in cilia and flagella. What function of the cytoskeleton is consistent with the presence of microtubules in these structures?

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Part III

Enhance your understanding of evolution and diversity through media and applications!

Media

Chapter 13 Darwin and Evolution
- **Animations** Evolution of Homologous Genes; Genetic Drift
- **Video** Finches—Natural Selection
- **Virtual Lab** Dinosaur Dig

Chapter 14 Speciation and Evolution
- **Videos** Finches—Adaptive Radiation; Cichlid Specialization

Chapter 15 The Evolutionary History of Life on Earth
- **Animations** Geological History of Earth; Breakup of Pangaea; Three Domains; Phylogenetic Tree
- **Video** Prehistoric Hurricanes
- **Virtual Lab** Classifying Using Biotechnology

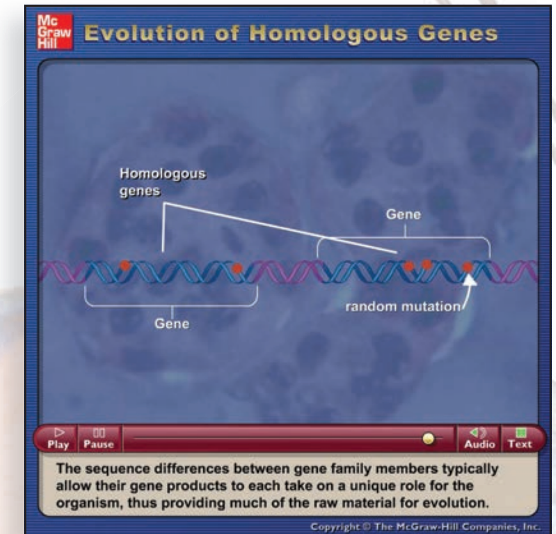
Chapter 16 Evolution of Microbial Life
- **Animations** How the HIV Infection Cycle Works; Prion Diseases; Binary Fission; Bacterial Spore Formation; Bacterial Transformation; Bacterial Conjugation: Transfer of a Plasmid
- **Videos** Virus Lytic Cycle; Virus Crisis; How Viruses Attack; Cranberries vs. Bacteria

Chapter 17 Evolution of Protists
- **Animations** Endosymbiosis; Malaria: Life Cycle of Plasmodium
- **Video** Plankton Diversity

Chapter 18 Evolution of Plants and Fungi
- **Videos** Carnivorous Plants; Spore Dispersal; Christmas Tree Threat

Chapter 19 Evolution of Animals
- **Animation** Early Vertebrates
- **Videos** Portuguese Man-of-War; Clam Locomotion; Sea Urchin Reproduction; Frog Reproduction; Walking Catfish; Trials of a Tadpole; Leaf-Tailed Gecko; Bird Radar; Mom Grizzly Teaches Her Cubs
- **Virtual Labs** Earthworm Dissection; Classifying Arthropods; Virtual Frog Dissection

Chapter 20 Evolution of Humans
- **Video** Tool Use by Chimps



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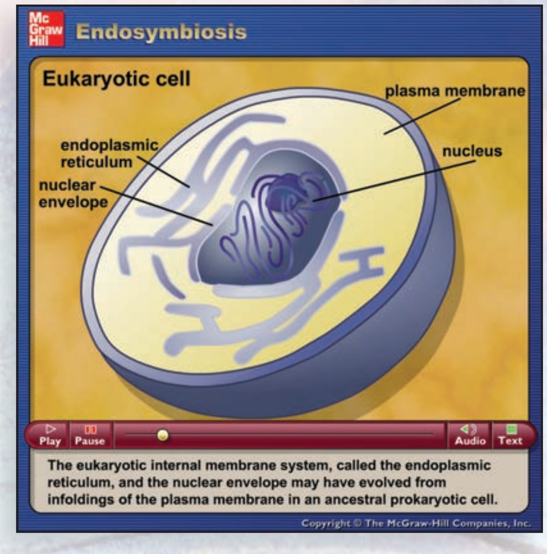
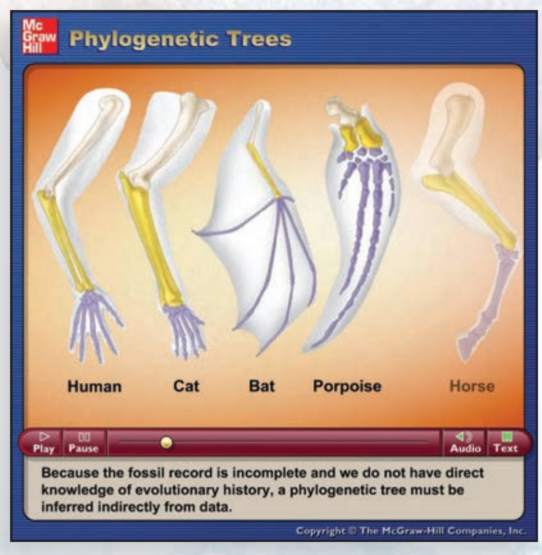
Organisms Are Related and Adapted to Their Environment





Applications

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13

Darwin and Evolution

CHAPTER OUTLINE

APPLICATIONS

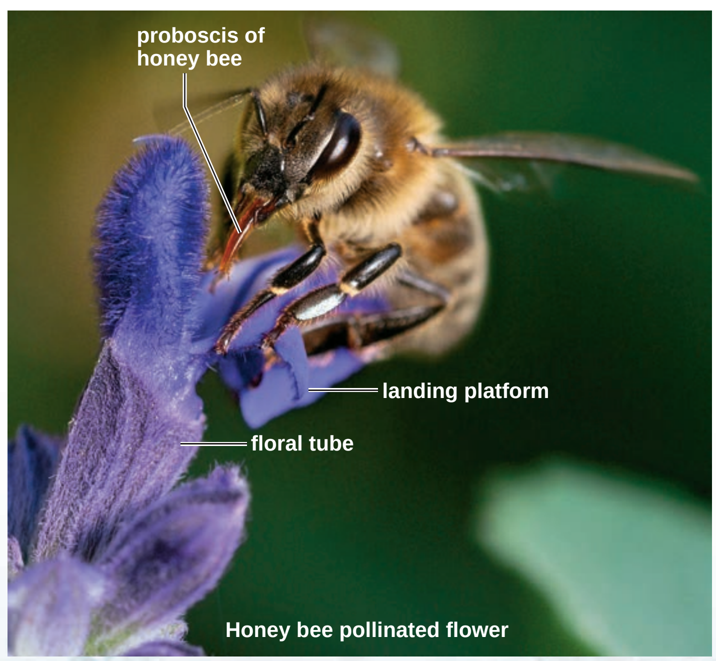
The "Vice Versa" of Animals and Plants

Adaptations provide powerful evidence for evolution. Bacteria that are able to survive and reproduce in the presence of an antibiotic have become adapted to their environment. Penguins are birds adapted to swimming in the ocean, and bats are mammals that can fly due to wings made of skin stretched over long fingers.

Insects are adapted to taking nectar from particular plants. It might seem as if bees go to all flowers, but they don't. They prefer sweet-smelling flowers with ultraviolet shadings that lead them to where nectar, a surgery liquid that serves as food, can be found. The bee feeding apparatus is a long, specialized tongue, called a proboscis, that is just the right size to reach down into a narrow floral tube where the nectar is located. As the bee goes about the business of feeding, pollen clings to its hairy body, and then as the bee moves from flower to flower of the species to which it is adapted, the pollen is distributed. Why does a flower provide the bee with nectar? By providing bees with nectar, flowers are helping to ensure their reproduction.

The orchid *Ophrys apifera* has a unique appearance that causes a bumblebee to visit it. The center of the flower looks like a female bumblebee is resting there. Actually, this is due to a petal that resembles a bumblebee. Occasionally, a male bee tries to mate with the petal, and when it does, it gets dusted with pollen, which the male bee takes to the next flower of this species.

Butterflies tend to feed from colorful composite flowers that provide them with a flat landing platform. Each individual flower of the composite has a floral tube that allows



Honey bee pollinated flower

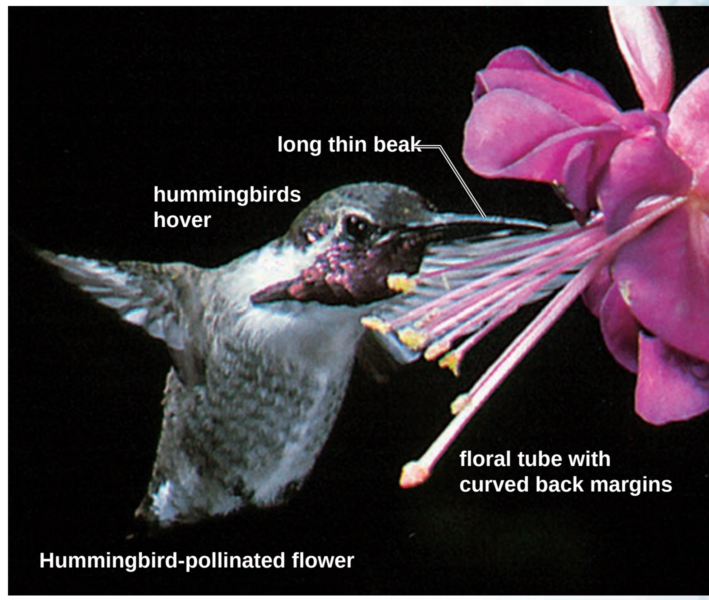
Bumblebee-pollinated flower, *Ophrys elegans*

the long, thin butterfly proboscis to reach the nectar. Hummingbirds flap their wings rapidly—called hovering—in order to remain in one spot while they feed during the day from odorless, red flowers that curve backward. A hummingbird's long, thin beak can access the nectar through a slender floral tube.

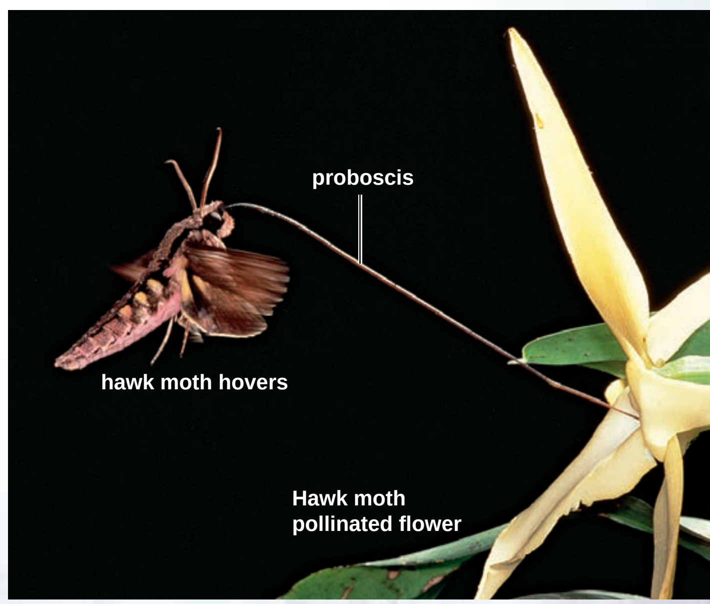
Moth-pollinated flowers are white, pale yellow, or pink—colors that are visible at night, when moths are active. The flowers give off a strong, sweet perfume that attracts moths, which hover as they extend a long, thin proboscis to gather the nectar at the base of a floral tube. The Madagascar star orchid (*Angraecum sesquipedale*) has a very long floral tube that holds its nectar much like a long, thin goblet would hold a drink. When Darwin first saw a picture of this orchid, he exclaimed, "What insect could suck it?" Later, he said in his book on orchids, "In Madagascar there must be moths with proboscises capable of an extension to ten and eleven inches [25.4 cm–27.7 cm]!" Many were skeptical, but Darwin was vindicated when in 1903, the zoologists Lionel Walter Rothschild and Karl Jordan discovered a large hawk moth living in Madagascar that has a proboscis 25–30 cm in length. As the hawk moth approaches the flower, it unrolls its proboscis and inserts it into the floral tube in order to feed.

We begin our study of evolution in this chapter by examining the work of Charles Darwin, who provided evidence that evolution consists of descent from a common ancestor and adaptation to the environment. Further, Darwin offered a mechanism for evolution he called natural selection. He called it natural selection because the environment, in a sense, chooses which members of a population reproduce, and in that way, adaptation to the environment is eventually achieved.

Butterfly-pollinated flower



Hummingbird-pollinated flower



Hawk moth pollinated flower

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Darwin Developed a Natural Selection Hypothesis

Learning Outcomes

- Name two early biologists who attempted to explain evolution but lacked a suitable mechanism. (13.1)
- Describe Darwin's trip aboard the HMS Beagle and some of the observations he made. (13.1)
- Give examples of artificial selection carried out by human beings. (13.2)
- Explain Darwin's hypothesis for natural selection. (13.3)
- Tell how Wallace's contribution paralleled that of Darwin's. (13.4)

Other scientists before Darwin hypothesized that evolution occurs, but developed no mechanism. Darwin concluded that evolution occurs after taking a trip around the world as a naturalist aboard the HMS *Beagle*. After studying artificial selection and the work of Thomas Malthus, Darwin—and later Alfred Wallace—suggested natural selection as a mechanism for evolution.

13.1 Darwin made a trip around the world

Biologists before Darwin had suggested that evolution occurs. Georges Cuvier, who founded the science of **paleontology,** the study of fossils, knew that fossils showed a succession of different life-forms through time (**Fig. 13.1A**). He hypothesized that a series of past catastrophes (local extinctions) had occurred and that after each one, a region was repopulated by species from surrounding areas. The result of all these catastrophes was change appearing over time.

In contrast to Cuvier, Jean-Baptiste de Lamarck, an invertebrate biologist, concluded on the basis of fossil evidence that more complex organisms are descended from less complex organisms. To explain the process of adaptation to the environment, Lamarck offered the idea of *inheritance of acquired characteristics,* which proposes that use and disuse of a structure can bring about inherited change. One example Lamarck gave—and the one for which he is most famous—is that the long neck of a giraffe developed over time because animals stretched their necks to reach food high in trees and then passed on a longer neck to their offspring (**Fig. 13.1B**).

Neither Cuvier nor Lamarck arrived at a satisfactory explanation for the evolutionary process. The inheritance of acquired characteristics has never been substantiated by experimentation. For example, if acquired characteristics were inherited, people who use tanning machines would have tan children, and people who have LASIK surgery to correct their vision would have children with perfect vision.

FIGURE 13.1A One of the animals that Cuvier reconstructed from fossils was the mastodon.

However, in December 1831, a new chapter in the history of biology began. A 22-year-old naturalist, Charles Darwin (1809–1882), set sail on the journey of a lifetime aboard the British naval vessel HMS *Beagle* (**Fig. 13.1C**). Darwin's primary mission on this journey around the world was to expand the navy's knowledge of natural resources in foreign lands. The captain of the *Beagle,* Robert Fitzroy, also hoped that Darwin would find evidence to support the biblical account of creation. Contrary to Fitzroy's wishes, Darwin amassed observations that would eventually support another way of thinking and change the history of science and biology forever.

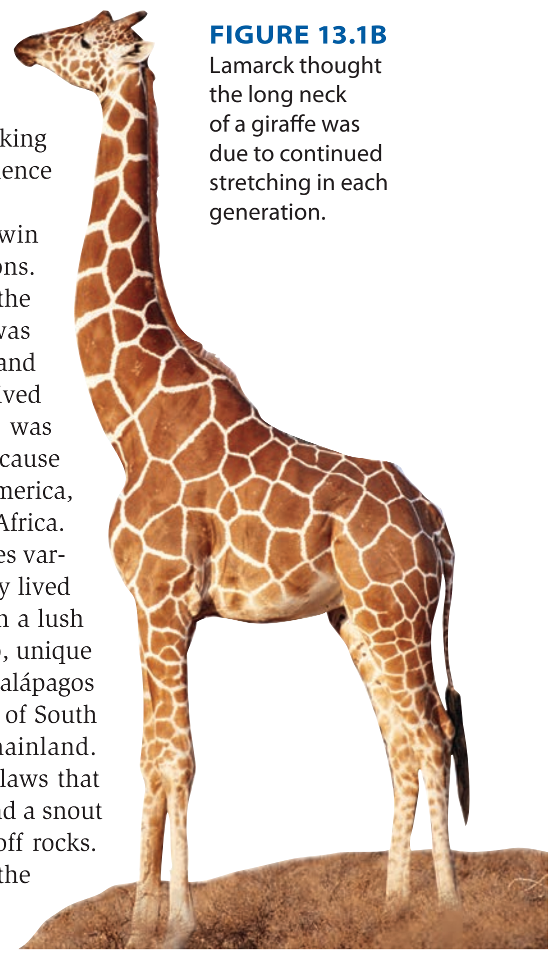

FIGURE 13.1B Lamarck thought the long neck of a giraffe was due to continued stretching in each generation.

During the trip, Darwin made numerous observations. For example, he noted that the rhea of South America was suited to living on a plain and looked like the ostrich that lived in Africa. However, the rhea was not an ostrich. Why not? Because the rhea evolved in South America, while the ostrich evolved in Africa. Darwin also found that species varied according to whether they lived in the Patagonian desert or in a lush tropical rain forest. Then, too, unique animals lived only on the Galápagos Islands, located off the coast of South America, not on the mainland. A marine iguana had large claws that allowed it to cling to rocks and a snout that enabled it to eat algae off rocks. One type of finch, lacking the long bill of a woodpecker, used a cactus spine to

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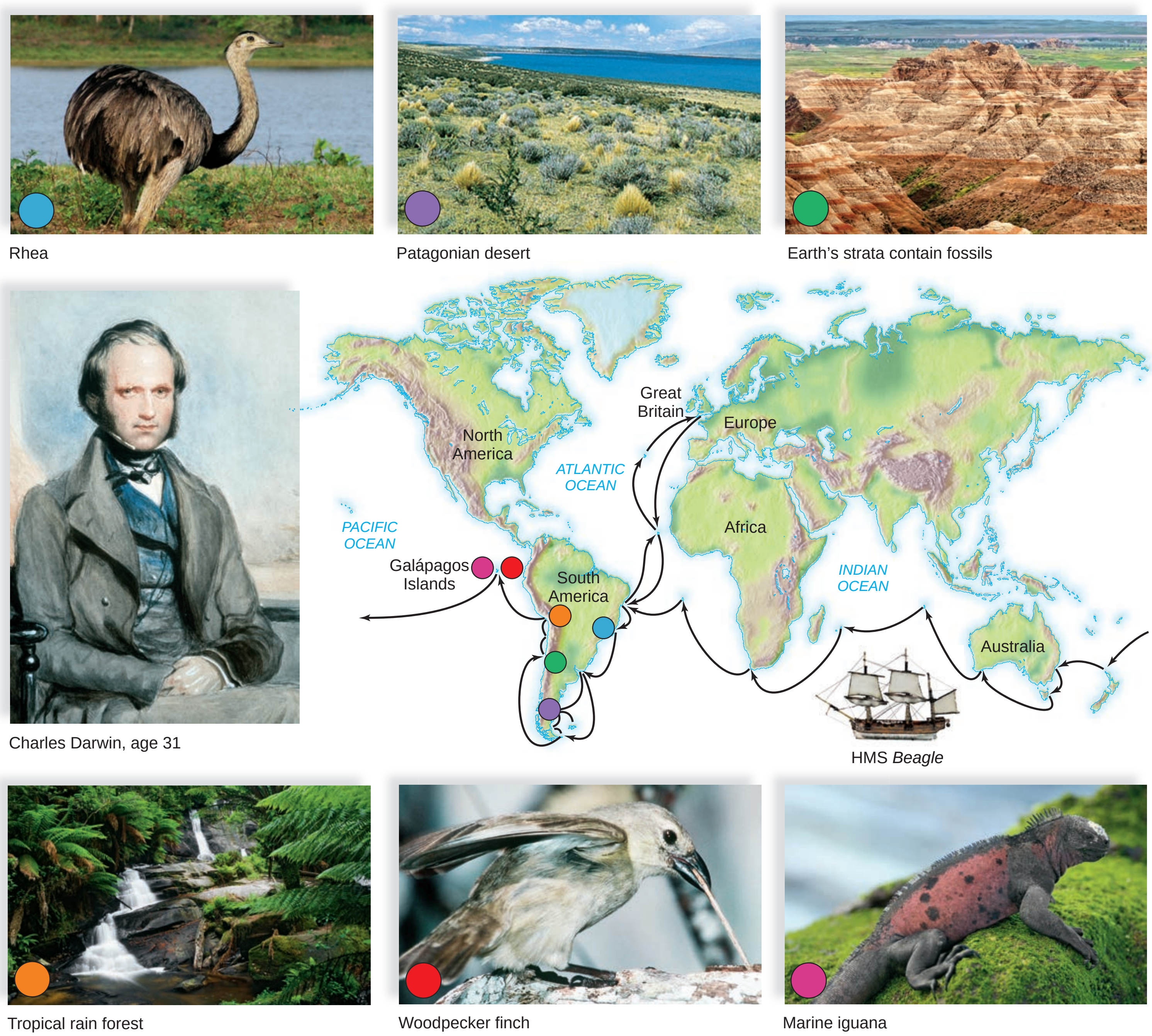

FIGURE 13.1C *Middle:* Charles Darwin and the route of the HMS *Beagle*. Circles pinpoint highlights of Darwin's trip.

probe for insects. Why were these animals found only in the Galápagos Islands? Had they evolved there?

When Darwin explored the region that is now Argentina, he saw raised beaches for great distances along the coast. He thought it would have taken a long time for such massive movements of the Earth's crust to occur. While Darwin was making geologic observations, he also collected fossils that showed today's plants and animals resemble, but are not exactly like, their forebears. Darwin had brought Charles Lyell's *Principles of Geology* on the *Beagle* voyage. This book said that weathering causes erosion and that, thereafter, dirt and rock debris are washed into the rivers and transported to oceans. When these loose sediments are deposited, layers of soil called **strata** (sing., stratum) result. The strata, which often contain fossils, are uplifted from below sea level to form land. Lyell's book went on to support a **uniformitarianism** hypothesis, which states that geologic changes occur at a uniform rate. This idea of slow geologic change is still accepted today, although modern geologists have concluded that rates of change have not always been uniform. Darwin was convinced that the Earth's massive geologic changes are the result of slow processes and that, therefore, in contrast to thought at that time, the Earth was old enough to have allowed *evolution* to occur.

13.1 Check Your Progress **Look again at Figure 1.1B, a diagram that illustrates the scientific method. Which part of the diagram applies to Darwin's approach so far?**

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13.2 Artificial selection mimics natural selection

Darwin made a study of **artificial selection,** a process by which humans choose, on the basis of certain traits, the animals and plants that will reproduce. For example, foxes are very shy and normally shun the company of people, but in 40 years time, Russian scientists have produced silver foxes that now allow themselves to be petted and even seek attention (**Fig. 13.2A**). They did this by selecting the most docile animals to reproduce. The scientists noted that some physical characteristics changed as well. The legs and tails became shorter, the ears became floppier, and the coat color patterns changed. Artificial selection is only possible because the original population exhibits a range of characteristics, allowing humans to select which traits they prefer to perpetuate.

To take another example, several varieties of vegetables can be traced to a single ancestor that exhibits various characteristics. Chinese cabbage, brussels sprouts, and kohlrabi are all derived from one species of wild mustard (**Fig. 13.2B**). Cabbage was produced by selecting for reproduction only plants that had overlapping leaves; brussels sprouts came from crossing only plants with certain types of buds; and kohlrabi was produced by crossing only the plants that had enlarged stems.

FIGURE 13.2A Artificial selection has produced domesticated foxes.

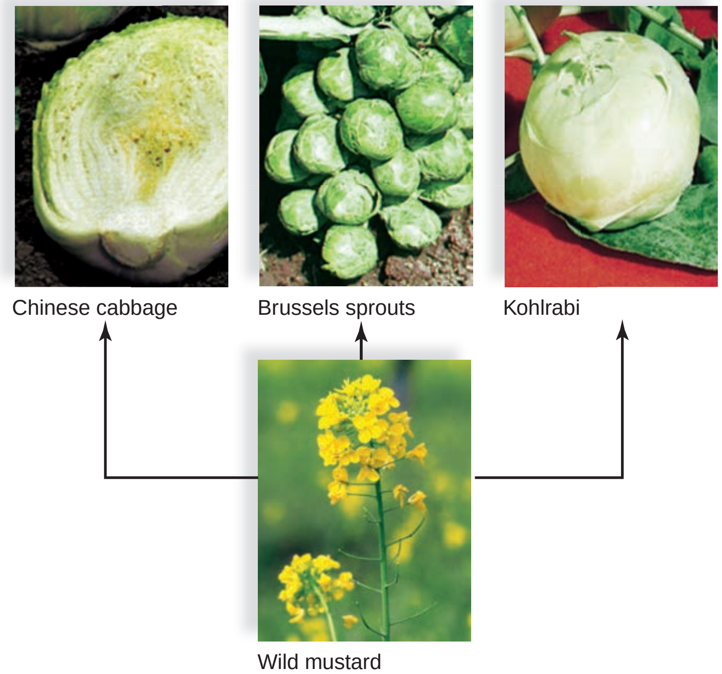

FIGURE 13.2B These three vegetables came from the wild mustard plant through artificial selection.

Darwin thought that a process of selection might occur in nature without human intervention. Using the process of artificial selection helped him arrive at the mechanism of natural selection, which allows evolution to occur.

In Section 13.3, we see that Darwin was also influenced by Thomas Malthus when he formulated natural selection as a mechanism for evolution.

13.2 Check Your Progress **If you wanted to use artificial selection to achieve a particular type of flower, would you allow the flower to pollinate naturally?**

13.3 Darwin formulated natural selection as a mechanism for evolution

Darwin was very much impressed by an essay written by Thomas Malthus about the reproductive potential of human beings. Malthus had proposed that death and famine are inevitable because the human population tends to increase faster than the supply of food. Darwin applied this concept to all organisms and saw that available resources were insufficient for all members of a population to survive. For example, he calculated the reproductive potential of elephants. Assuming a life span of about 100 years and a breeding span of 30–90 years, a single female probably bears no fewer than six young. If all these young survive and continue to reproduce at the same rate, after only 750 years, the descendants of a single pair of elephants would number about 19 million! Each generation has the same reproductive potential as the previous generation. Therefore, Darwin hypothesized, there is a constant struggle for existence, and only certain members of a population survive and reproduce in each generation. What members might those be? The members that have some advantage and are best able to compete successfully for limited resources.

Applying Darwin's thinking to giraffes, we can see that long-necked giraffes would be better able to feed off leaves in trees than short-necked giraffes. The longer neck gives giraffes an advantage that, in the end, would allow them to produce more offspring than short-necked giraffes. So, eventually, all the members of a giraffe population (individuals of a species in one locale) would have long necks. Or, what about bacteria living in an environment of antibiotics? The few bacteria that can survive in this environment have a tremendous advantage, and therefore their offspring will make up the next generation of bacteria, and this strain of bacteria will be resistant to the antibiotic.

Darwin called the process by which organisms with an advantage reproduce more than others of their kind **natural**

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selection because some aspect of the environment acts as a **selective agent** and chooses the members of the population with the advantageous phenotype to reproduce more than the other members.

Natural selection has these essential components:

- *The members of a population have inheritable variations.* For example, a wide range of differences exists among the members of a population. Many of these variations are inheritable. Inheritance of variations is absolutely essential to Darwin's hypothesis, even though he did not know the means by which inheritance occurs.
- *A population is able to produce more offspring than the environment can support.* The environment contains only so much food and water, places to live, potential mates, and so forth. The environment can't support all the offspring that a population can produce, and each generation is apt to be too large for the environment to support.
- *Only certain members of the population survive and reproduce.* Certain members have an advantage suited to the environment that allows them to capture more resources than other members, as when long-necked giraffes are better able to browse on tree leaves. This advantage allows these members of the population to survive and produce more offspring. This is called differential reproduction because the members of a population differ as to how many surviving offspring they will have.
- *Natural selection results in a population adapted to the local environment.* In each succeeding generation, an increasing proportion of individuals will have the adaptive characteristics—the characteristics suited to surviving and reproducing in that environment (**Fig. 13.3**).

FIGURE 13.3 The brightly colored tree frog can hide among tropical plants where the large red eyes confuse predators. The frog climbs trees and other plants assisted by toes with suction cups.

Now it is possible to form a definition of evolution. **Evolution** consists of changes in a population over time due to the accumulation of inherited differences. Evolution explains the unity and diversity of organisms. "Unity" means organisms share the same characteristics of life because they share a common ancestry, traceable even to the first cell or cells. "Diversity" comes about because each type of organism (each species) is adapted to one of the many different environments in the biosphere (e.g., oceans, deserts, mountains, etc.).

Independently, Alfred Wallace also arrived at natural selection as a mechanism for evolution, as explained next.

13.3 Check Your Progress **Why is it advantageous for a plant to have a flower structure suited to a particular pollinator?**

13.4 Wallace independently formulated a natural selection hypothesis

Like Darwin, Alfred Russel Wallace (1823–1913) was a naturalist. While he was a schoolteacher at Leicester in 1844–1845, he met Henry Walter Bates, a biologist who interested him in insects. Together, they went on a collecting trip to the Amazon that lasted several years. Wallace's knowledge of the world's flora and fauna was further expanded by a tour he made of the Malay Archipelago from 1854 to 1862. Later, he divided the islands into a western group and an eastern group on the basis of their different plants and animals. The dividing line between these islands is a narrow but deep strait now known as the Wallace Line.

Just as Darwin had done, Wallace wrote articles and books that clearly showed his belief that species change over time and it was possible for new species to evolve. Later, he said he had pondered for many years about a mechanism to explain the origin of a species. He, too, had read Malthus's essay on human population increases, and in 1858, while suffering an attack of malaria, the idea of "survival of the fittest" came upon him. He quickly completed an essay outlining a natural selection process, which he chose to send to Darwin for comment. Darwin was stunned upon its receipt. Here before him was the hypothesis he had formulated as early as 1844, but never published. Darwin told his friend and colleague Charles Lyell that Wallace's ideas were so similar to his own that even Wallace's "terms now stand as heads of my chapters" in the book he had begun in 1856.

Darwin suggested that Wallace's paper be published immediately, even though he himself had nothing in print yet. Lyell and others who knew of Darwin's detailed work substantiating the process of natural selection suggested that a joint paper be read to the Linnean Society. The title of Wallace's section was "On the Tendency of Varieties to Depart Indefinitely from the Original Type." Darwin allowed the abstract of a paper he had written in 1844 and an abstract of his book *On the Origin of Species* to be read. This book was published in 1859.

By now, evolution by natural selection has been supported by so many observations and experiments that it is considered a theory rather than a hypothesis. Modern investigators have shown that it is possible to observe the process of natural selection, as described in the How Science Progresses on the next page.

13.4 Check Your Progress **Did the work of Wallace lend support to the natural selection hypothesis? Explain.**

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13A Natural Selection Can Be Witnessed

Darwin formed his natural selection hypothesis, in part, by observing the adaptations of tortoises and finches on the Galápagos Islands. Tortoises with domed shells and short necks live on well-watered islands, where grass is available. Those with shells that flare up in front have long necks and are able to feed on tall cacti. They live on arid islands, where treelike prickly-pear cactus is the main food source. Similarly, the islands are home to many different types of finches (**Fig. 13A.1**). The heavy beak of the large, ground-dwelling finch is suited to a diet of seeds. The beak of the warbler-finch is suited to feeding on insects found among ground vegetation or caught in the air. The longer, somewhat more pointed beak and split tongue of the cactus-finch are suited for probing cactus flowers for nectar.

A ground-dwelling finch feeds on seeds.

A cactus-finch probes flowers for nectar.

A warbler-finch feeds on insects.

FIGURE 13A.1 Finches on the Galápagos Islands.

Beak Size and Natural Selection

Today, investigators, such as Peter and Rosemary Grant of Princeton University, are actually watching natural selection as it occurs. In 1973, the Grants began a study of the various finches on Daphne Major, near the center of the Galápagos Islands. The weather swung widely back and forth from wet years to dry years, and they found that the beak size of the medium ground finch, *Geospiza fortis,* adapted to each weather swing, generation after generation (**Fig. 13A.2**). These finches like to eat small, tender seeds that require a smaller beak, but when the weather turns dry, they have to eat larger, drier seeds, which are harder to crush. Then, the birds that have a larger beak depth have an advantage and produce more offspring. Dry weather acts as a selective agent for a *G. fortis* beak size that has more depth than in the previous generation.

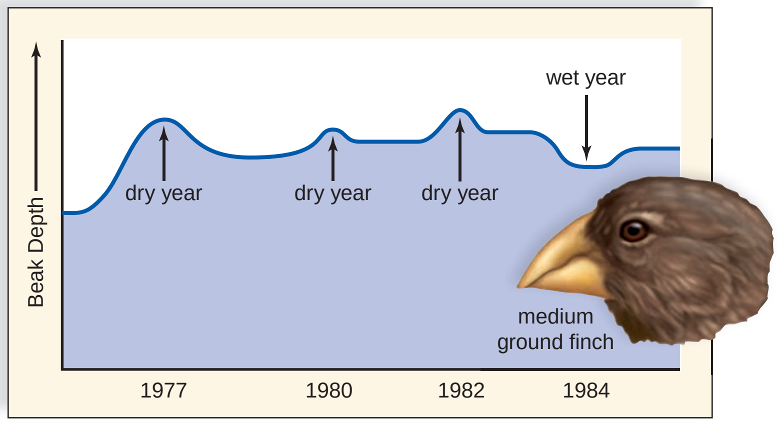

FIGURE 13A.2 The beak size of a ground finch varies from generation to generation, according to the weather.

Silent Crickets and Natural Selection

A research team led by Marlene Zuk, a professor of biology, reported that prior to 2001 the Hawaiian field cricket population *(Teleogryllus oceanicus)* on the island of Kauai contained very few silent males. Chirping males have a wing structure that produces the chirping sound that attracts females. By 2006, over 90% of male crickets were silent because their wings were flat and unable to produce the chirping sound. In just 20 generations, the population had undergone this dramatic evolutionary change due to a particular selective agent that caused the silent phenotype to be advantageous. A deadly parasitic fly *(Ormia ochracea)* uses the male crickets' chirping as a way to locate them. The fly deposits her eggs on a male cricket's back, and they develop into maggots. Over a week's time, the maggots eat the cricket's internal organs and then emerge from its dead body to undergo metamorphosis into adult flies. The silent males were not parasitized and increased in number because many of them mated with females and passed on their genes. How did they do it? The silent males wait near any remaining chirping males and intercept incoming females. Normally, female crickets will not accept a male until he completes a final mating song, but even that is beginning to change and females will now accept silent males, thereby allowing them to increase in number.

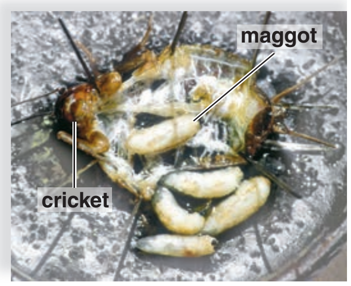

FIGURE 13A.3 Maggots feeding on a cricket.

FORM YOUR OPINION

1. Cite some examples of natural selection that involve resistance to drugs or pesticides. Now that we know how powerful natural selection can be, how can we keep resistance from happening?
2. Today's drug designers biochemically create drugs for a particular purpose, and then they keep testing and selecting which ones to improve. Is this natural selection at work?

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The Evidence for Evolution Is Strong

Learning Outcomes

- Tell why fossils offer powerful evidence for common descent. (13.5–13.6)
- Discuss anatomic, biogeographic, and molecular evidence for common descent. (13.7–13.9)

The evidence for evolution is categorized according to its source. Evidence for common descent is based on fossils, comparative anatomy, biogeography, and molecular observations.

13.5 Fossils provide a record of the past

The best evidence for evolution comes from **fossils,** the physical remains of organisms that lived on Earth between 10,000 and billions of years ago. Usually when an organism dies, the soft parts are either consumed by scavengers or decomposed by bacteria. This means that most fossils consist of hard parts, such as shells, bones, or teeth, because these are usually not consumed or destroyed. Fossils are also the traces of past life, such as trails, footprints, burrows, worm casts, or even preserved droppings. Or fossils can also be such items as pieces of bone, impressions of plants pressed into shale, organisms preserved in ice, and even insects trapped in tree resin (which we know as amber).

More and more fossils have been found because paleontologists have been out in the field looking for them (**Fig. 13.5A*a***). Weathering and erosion of rocks produces an accumulation of particles that vary in size and nature and are called sediment. This process, called sedimentation, has been going on since the Earth was formed, and can take place on land or in bodies of water. Sediment becomes a stratum, a recognizable layer in a sequence of layers. Any given stratum is older than the one above it and younger than the one immediately below it (Fig. 13.5A*b*). For a fossil to be encased by rock, the remains are first buried in sediment; then the hard parts are preserved by a process called mineralization; and finally, the surrounding sediment hardens to form rock.

Usually, paleontologists remove fossils from the strata to study them in the laboratory (**Fig. 13.5B**), and then they may decide to exhibit them. The **fossil record** is the history of life recorded by fossils and the most direct evidence we have that evolution has occurred. The species found in ancient sedimentary rock are not the species we see about us today.

FIGURE 13.5B Fossils are carefully cleaned, and organisms are reconstructed.

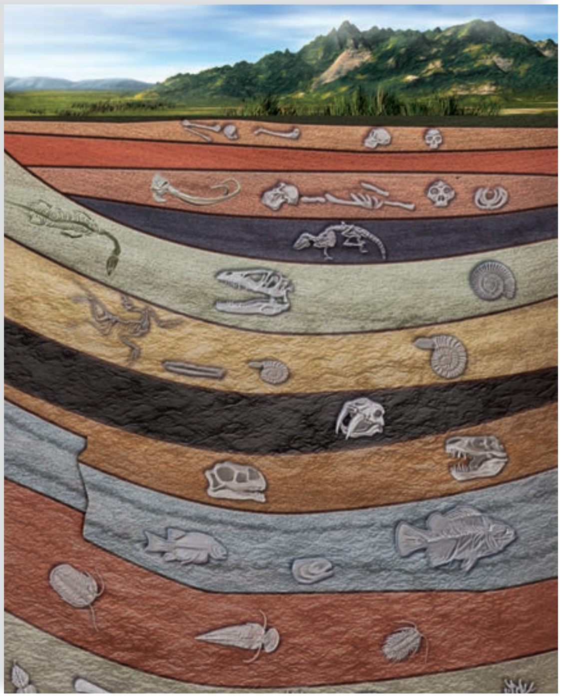
Darwin relied on fossils to formulate his theory of evolution, but today we have a far more complete record than was available to Darwin. The record tells us that, in general, life has progressed from the simple to the complex. Unicellular prokaryotes are the first signs of life in the fossil record, followed by unicellular eukaryotes and then multicellular eukaryotes. Among the latter, fishes evolved before terrestrial plants and animals. On land, nonflowering plants preceded the flowering plants, and amphibians preceded the reptiles, including the dinosaurs. Dinosaurs are directly linked to the evolution of birds, but only indirectly linked to the evolution of mammals, including humans.

13.5 Check Your Progress **Why would it be difficult to find fossils of flowers?**

FIGURE 13.5A **a.** Paleontologists carefully remove and study fossils. **b.** The deeper the stratum, the older the fossils found there.

a.

b.



13.6 Fossils are evidence for common descent

Darwin used the phrase "descent with modification" to explain evolution. Because of descent, all living things can trace their ancestry to an original source. For example, you and your cousins have a **common ancestor** in your grandparents and also in your great grandparents, and so forth. In the end, one couple can give rise to a great number of descendants.

A **transitional fossil** is either a common ancestor for two different groups of organisms or an individual closely related to the common ancestor for these groups. Transitional fossils allow us to trace the descent of organisms. Even in Darwin's day, scientists knew of the *Archaeopteryx lithographica* fossil, which is an intermediate between reptiles and birds. The dinosaurlike skeleton of these fossils has reptilian features, including jaws with teeth, and a long, jointed tail, but *Archaeopteryx* also had feathers and wings. **Figure 13.6A** shows a fossil of *Archaeopteryx* along with an artist's representation of the animal based on the fossil remains. Many more prebird fossils have been discovered recently in China. These fossils are progressively younger than *Archaeopteryx:* The skeletal remains of *Sinornis* suggest it had wings that could fold against its body like those of modern birds, and its grasping feet had an opposable toe, but it still had a tail. Another fossil, *Confuciusornis,* had the first toothless beak. A third fossil, called *Iberomesornis,* had a breastbone to which powerful flight muscles could attach. Such fossils show how the bird of today evolved.

Archaeopteryx fossil

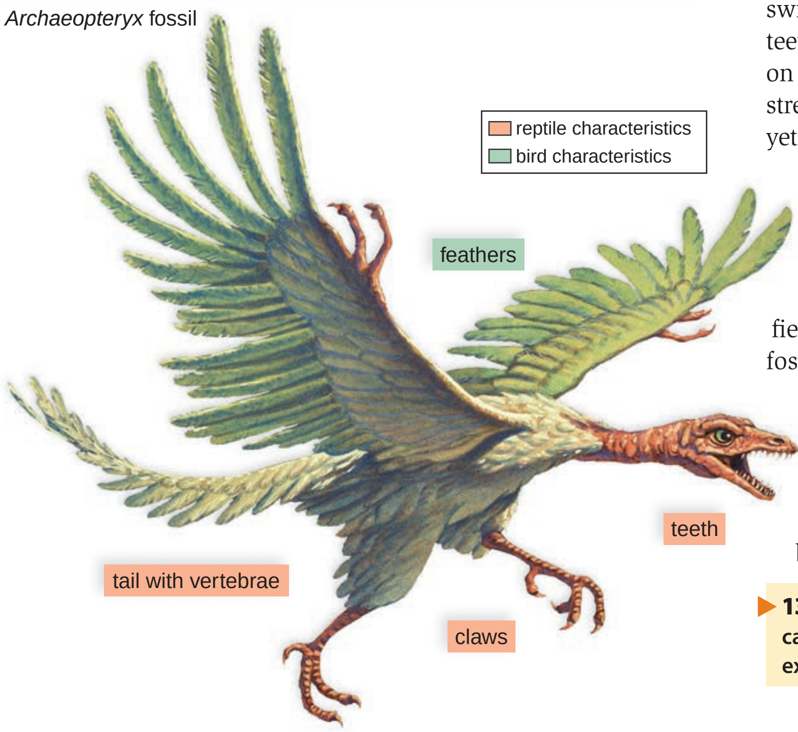


FIGURE 13.6A Fossil of *Archaeopteryx* and an artist's representation.

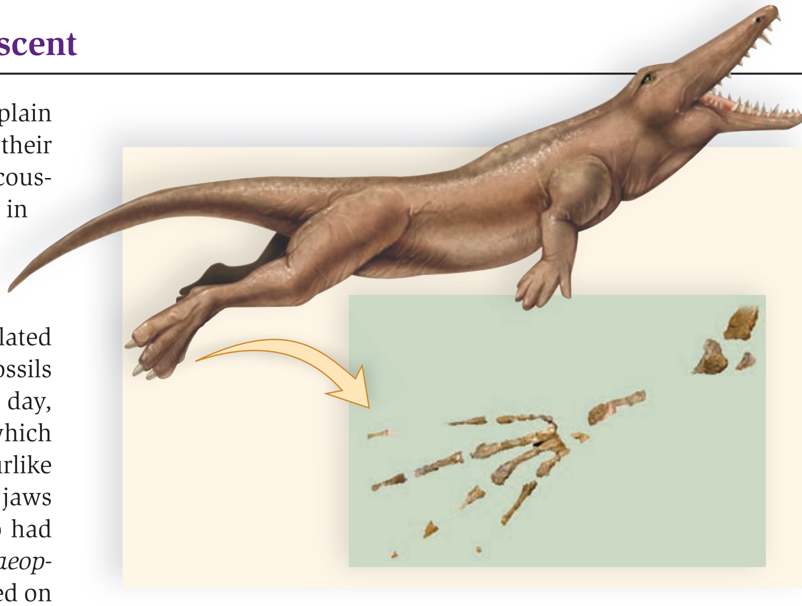


FIGURE 13.6B *Ambulocetus natans,* an ancestor of the modern toothed whale, and its fossil remains.

Scientists had always thought whales had terrestrial ancestors. Now, fossils have been discovered that support this hypothesis (see Fig. 14.1A). *Ambulocetus natans* (meaning "the walking whale that swims") was the size of a large sea lion, with broad, webbed feet on its forelimbs and hindlimbs that enabled it to both walk and swim. It also had tiny hoofs on its toes and the primitive skull and teeth of early whales. **Figure 13.6B** is an artist's re-creation, based on fossil remains of *Ambulocetus,* which lived in freshwater streams. An older genus, *Pakicetus,* was primarily terrestrial, and yet also had the dentition of an early toothed whale. A younger genus, *Rodhocetus,* had reduced hindlimbs that would have been no help for either walking or swimming, but may have been used for stabilization during mating.

The origin of mammals is also well documented. The synapsids are proto-mammals whose descendants diversified into different types of premammals. Slowly, mammal-like fossils acquired skeletal features that adapted them to live more efficiently on land. For example, the legs projected downward rather than to the side as in reptiles. The earliest true mammals were shrew-sized creatures that have been unearthed in fossil beds about 200 million years old.

Section 13.7 discusses the evidence for common descent based on comparative anatomy.

13.6 Check Your Progress Suppose fossils of hummingbirds indicated they had shorter, thicker beaks than at present. What would you expect to find about the flowers they pollinated?

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13.7 Anatomic evidence supports common descent

Anatomic similarities exist between fossils and between living organisms. Darwin was able to show that a common descent hypothesis offers a plausible explanation for anatomic similarities among organisms. Structures that are anatomically similar because they are inherited from a recent common ancestor are called **homologous structures.** In contrast, **analogous structures** are structures that serve the same function but are not constructed similarly, nor do they share a *recent* common ancestor. The wings of birds and insects and the eyes of octopuses and humans are analogous structures. The presence of homology, not analogy, is evidence that organisms are closely related. Studies of comparative anatomy and embryologic development and increasingly genetic data reveal homologous structures. For example, we now know that the gene *Pax6* (see Section 11.4, p. 216.) initiates the development of the eye in diverse organisms. Does this mean that all eyes are homologous structures instead of analogous ones?

Comparative Anatomy Vertebrate forelimbs are used for flight (birds and bats), orientation during swimming (whales and seals), running (horses), climbing (arboreal lizards), or swinging from tree branches (monkeys). Yet, despite their dissimilar functions all vertebrate forelimbs contain the same sets of bones organized in similar ways (**Fig. 13.7A**). The most plausible explanation for this unity is that the basic forelimb plan belonged to a common ancestor for all vertebrates, and then the plan was modified as each type of vertebrate continued along its own evolutionary pathway.

Vestigial structures are fully developed in one group of organisms but reduced and possibly nonfunctional in similar groups. For example, modern whales have a vestigial pelvic girdle and legs because their ancestors walked on land. Similarly, snakes have no use for hindlimbs, and yet some have remnants of a pelvic girdle and legs. Humans have a tailbone but no tail. The presence of vestigial structures can be explained by the common descent hypothesis: Vestigial structures occur because organisms inherit their anatomy from their ancestors; they are traces of an organism's evolutionary history.

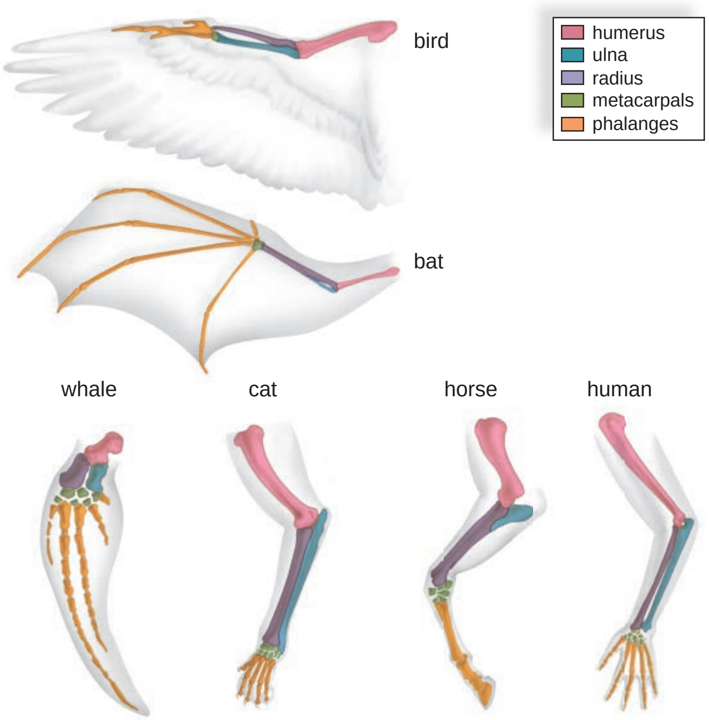

FIGURE 13.7A Despite differences in structure and function, vertebrate forelimbs have the same bones.

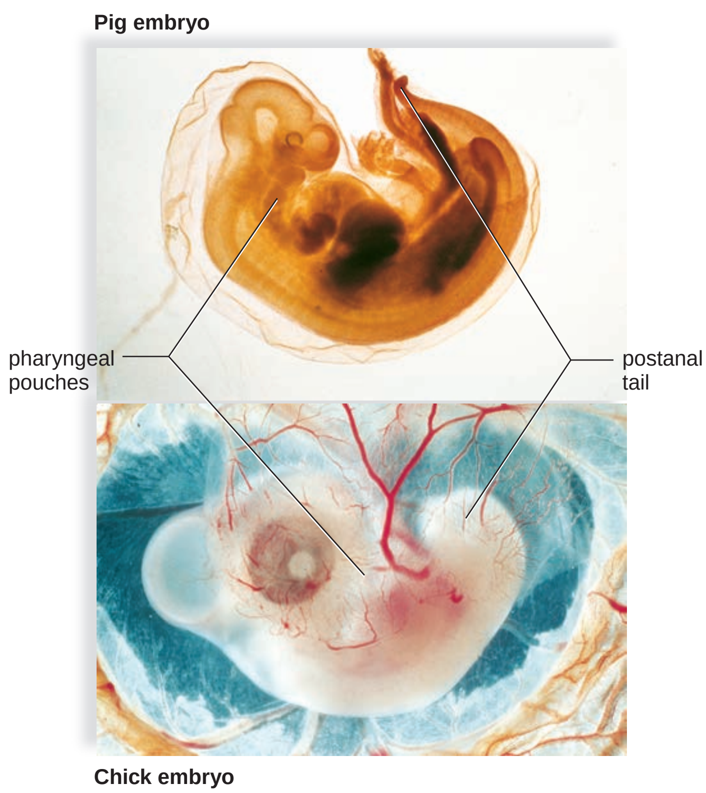

FIGURE 13.7B Vertebrate embryos have features in common, even though they have different appearances as adults.

Embryological Evidence The homology shared by vertebrates extends to their embryologic development. At some time during development, all vertebrates have a postanal tail and paired pharyngeal pouches (**Fig. 13.7B**). In fishes and amphibian larvae, these pouches develop into functioning gills. In humans, the first pair of pouches becomes the cavity of the middle ear and the auditory tube. The second pair becomes the tonsils, while the third and fourth pairs become the thymus and parathyroid glands. Why do terrestrial vertebrates develop and then modify structures such as pharyngeal pouches that have lost their original function? The most likely explanation is that terrestrial vertebrates can trace their ancestry to amphibians and then to fishes. Similarly, embryonic evidence tells us that echinoderms and vertebrates share a common ancestor because they both have the same early pattern of development (see Fig. 19.3).

▶ **13.7 Check Your Progress** **What type of ancestry would explain why two species of flowers have exactly the same type of floral tube?**

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13.8 Biogeographic evidence supports common descent

Biogeography is the study of the distribution of plants and animals in different places throughout the world. Because life-forms evolved in a particular locale, you would expect a different mix of plants and animals whenever geography separates continents, islands, or seas. As mentioned, Darwin noted that South America lacked rabbits. He concluded that no rabbits lived in South America (even though the environment was quite suitable for them) because rabbits evolved somewhere else and had no means of reaching South America. Instead, the Patagonian hare resembles a rabbit in anatomy and behavior but has the face of a guinea pig, from which it probably evolved in South America.

To take another example, both cactuses and euphorbia are succulent, spiny, flowering plants adapted to a hot, dry environment. Why do cactuses grow in North American deserts and euphorbia grow in African deserts, when each would do well on the other continent? It seems obvious that they just happened to evolve on their respective continents.

In the history of our planet, South America, Antarctica, and Australia were originally one continent. Marsupials (pouched mammals) arose at around the time Australia separated and drifted away on its own. Isolation allowed marsupials to diversify into many different forms suited to various environments of Australia. They were free to do so because there were few, if any, placental (modern) mammals in Australia. In South America, where there are placental mammals, marsupials are present but they are not as diverse. This supports the hypothesis that evolution is influenced by the mix of plants and animals in a particular continent—that is, by biogeography, not by design.

Section 13.9 discusses the molecular evidence for common descent.

13.8 Check Your Progress Explain the observation that the Galápagos Islands host many species of finches that are not found on the mainland.

13.9 Molecular evidence supports common descent

Almost all organisms use the same basic biochemical molecules, including DNA (deoxyribonucleic acid), ATP (adenosine triphosphate), and many identical or nearly identical enzymes. Further, all organisms use the same DNA triplet code and the same 20 amino acids in their proteins. Since the sequences of DNA bases in the genomes of many organisms are now known, it has become clear that humans share a large number of genes with much simpler organisms. Also of interest, evolutionists who study development have found that many developmental genes are shared by animals ranging from worms to humans. It appears that life's vast diversity has come about largely by differences in the regulation of genes. The result has been widely divergent types of bodies. For example, a similar gene in arthropods and vertebrates determines the dorsal-ventral axis. Although the base sequences are similar, the genes have opposite effects. Therefore, in arthropods, such as fruit flies and crayfish, the nerve cord is ventral, whereas in vertebrates, such as chicks and humans, the nerve cord is dorsal. The nerve cord eventually gives rise to the spinal cord and brain.

When the degree of similarity in DNA base sequences or the degree of similarity in amino acid sequences of proteins is examined, the data are consistent with our knowledge of evolutionary descent through common ancestors. Cytochrome *c* is a molecule that is used in the electron transport chain of many organisms. Data show that the amino acid sequence of cytochrome *c* in a monkey differs from that in humans by only two amino acids, from that in a duck by 11 amino acids, and from that in a yeast by 51 amino acids (**Fig. 13.9**), as you might expect from anatomic data.

This completes our study of the evidence supporting evolution. The next part of the chapter discusses how it is possible to determine that evolution, on a small scale, has occurred.

13.9 Check Your Progress Explain the observation that all organisms use DNA as their genetic material.

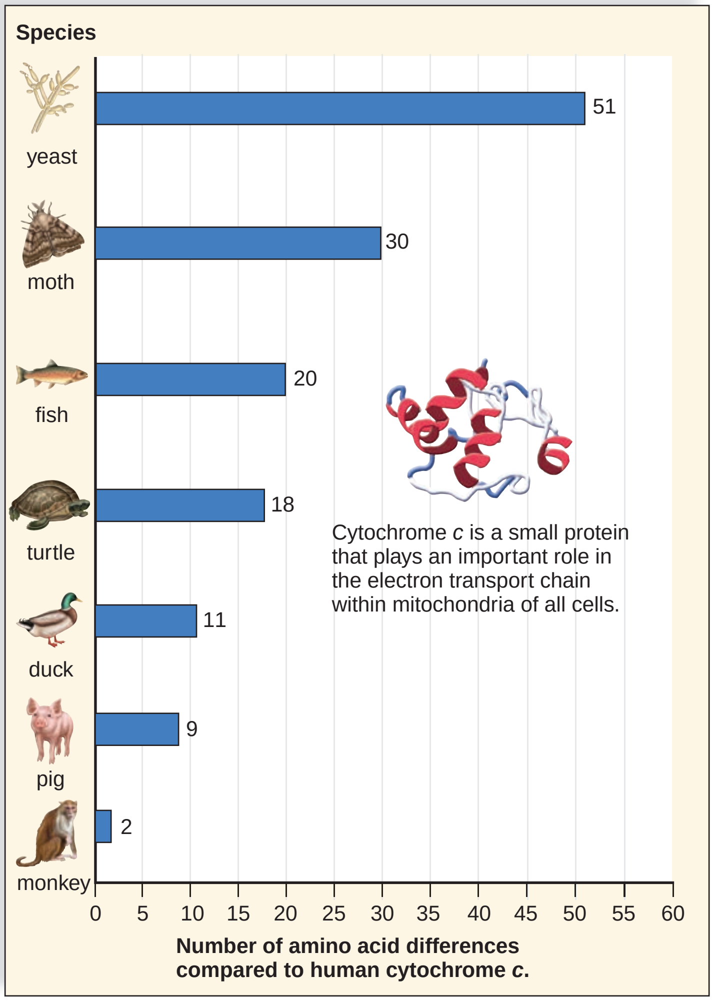

FIGURE 13.9 Biochemical differences indicate degrees of relatedness among organisms.

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Population Genetics Tells Us When Microevolution Occurs

Learning Outcomes

- Tell how the human population has microvariations. (13.10)
- Use the Hardy-Weinberg principle to explain when microevolution occurs. (13.11)
- Explain how mutations, nonrandom mating, gene flow, genetic drift, and natural selection contribute to the process of microevolution. (13.12–13.15)
- Name three kinds of natural selection, and discuss the effect of each on a population. (13.15)
- Give an example to show that stabilizing selection can maintain heterozygotes in a population. (13.16)

Microevolution is evolution beneath the species level. The Hardy-Weinberg principle states that allele frequencies in a population, calculated by using the equation $p^2 + 2\,pq + q^2$, will stay constant generation after generation, unless evolution occurs. Usually evolution, defined as an allele frequency change, does occur.

13.10 The human population is diverse

Darwin stressed that diversity exists among the members of a population. A **population** is all the members of a single species occupying a particular area at the same time; even the human population has local populations (**Fig. 13.10**). All humans are the same species, as can be witnessed by the fact that any two ethnicities can reproduce and produce healthy offspring. Genomic studies have allowed investigators to discover that much of the genomic diversity of humans is due to microvariations such as **single nucleotide polymorphisms** (differences), or **SNPs** (pronounced "snips"). These are DNA sequences that differ by a single nucleotide. For example, compare ACGTACGTA to ACGTACCTA and notice that there is only a single base difference between the two sequences. Investigators would say that the SNP has two alleles—in this case, G and C. SNPs generally have two alleles.

SNPs that occur within a protein-coding DNA sequence may or may not result in a changed sequence of amino acids, due to the redundancy of the genetic code (see Fig. 10.4B). SNPs that do not result in a changed amino acid sequence may still cause regulatory differences. Therefore, SNPs are now thought to be an important source of genetic diversity among humans. Another interesting finding is that humans inherit patterns of base sequence differences now called haplotypes (from the terms haploid and genotype). To take an example, if a chromatid has a G rather than a C at a particular location, this change is most likely accompanied by other base differences near the G. Researchers are in the process of discovering the most common haplotypes among African, Asian, and European populations. They want to link haplotypes to the risk of specific illnesses, hoping this will lead to new methods of preventing, diagnosing, and treating disease. Also, certain haplotypes may respond better than others to particular medicines, vaccines, and other treatment strategies.

13.10 Check Your Progress **Why is it important for the members of a population to be both genetically similar but also different?**

FIGURE 13.10 The HapMap project compares DNA sequences among African, Asian, and European populations to discover unique base sequence differences.

13.11 A Hardy-Weinberg equilibrium is not expected

Not until the 1930s were population geneticists able to apply the principles of genetics to populations and thereafter develop a way to recognize when microevolution has occurred. The **gene pool** of a population is composed of all the alleles in all the individuals making up the population. When the allele frequencies for a population change, microevolution has occurred. Microevolution does not necessarily result in a visible change but let's take an example that does.

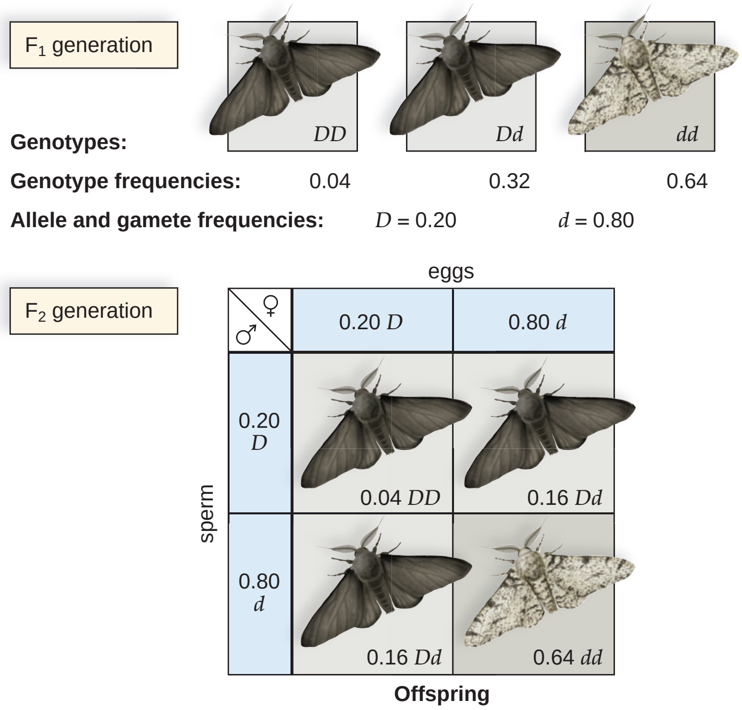
A peppered moth can be light-colored or dark-colored. Suppose you research the literature and find that the color of peppered moths is controlled by a single set of alleles, and you decide to use the following key: D = dark color and d = light color. Furthermore, you find that in one Great Britain population, only 4% (0.04) of the moths are homozygous dominant (DD), 32% (0.32) are heterozygous (Dd), and 64% (0.64) are homozygous recessive (dd). From these genotype frequencies, you can calculate the allele frequencies, in the population:

genotypes	DD	Dd	dd
frequency of genotypes in the population	0.04	0.32	0.64
frequency of alleles and gametes in the population	0.04 + 0.16 = 0.20 D		0.16 + 0.64 = 0.80 d

The frequency of the gametes (sperm and egg) produced by this population will necessarily be the same as the allele frequencies. Assuming random mating (all possible gametes have an equal chance to combine with any other), we can use these gamete frequencies to calculate the ratio of genotypes in the next generation by using a Punnett square (**Fig. 13.11**).

There is an important difference between a Punnett square that represents a cross between individuals and the one shown in Figure 13.11. In Figure 13.11, we are using the gamete frequencies in the population to determine the genotype frequencies in the next generation. As you can see, the results show that the genotype frequencies (and therefore the allele frequencies) in the next generation are the same as they were in the previous generation. In other words, the homozygous dominant moths are still 0.04; the heterozygous moths are still 0.32; and the homozygous recessive moths are still 0.64 of the population. This remarkable finding tells us that *sexual reproduction alone cannot bring about a change in genotype and allele frequencies.* Also, the dominant allele need not increase from one generation to the next. Dominance does not cause an allele to become a common allele.

The potential constancy, or equilibrium state, of gene pool frequencies was independently recognized in 1908 by G. H. Hardy, an English mathematician, and W. Weinberg, a German physician. They used the binomial equation ($p^2 + 2pq + q^2 = 1$) to calculate the genotype and allele frequencies of a population, as illustrated in Figure 13.11. From their findings, they formulated the **Hardy-Weinberg principle,** which states that an equilibrium of allele frequencies in a gene pool will remain in effect in each succeeding generation of a sexually reproducing population as long as five conditions are met:



Genotype frequencies: 0.04 DD + 0.32 Dd + 0.64 dd = 1

$\boldsymbol{p^2 + 2pq + q^2 = 1}$

p^2 = frequency of DD genotype (dark-colored) = $(0.20)^2$ = 0.04

$2pq$ = frequency of Dd genotype (dark-colored) = 2(0.20)(0.80) = 0.32

q^2 = frequency of dd genotype (light-colored) = $(0.80)^2$ = 0.64

1.00

FIGURE 13.11 Calculating gene pool frequencies for F_1 and F_2.

1. No mutations: Allele changes do not occur, or changes in one direction are balanced by changes in the opposite direction.
2. No gene flow: Migration of alleles into or out of the population does not occur.
3. Random mating: Individuals pair by chance, not according to their genotypes or phenotypes.
4. No genetic drift: The population is very large, and changes in allele frequencies due to chance alone are insignificant.
5. No natural selection: No selective agent favors one genotype over another.

In real life, these conditions are rarely met, if ever, and allele frequencies in the gene pool of a population do change from one generation to the next. For example, when the trees darken due to industrial pollution, gene pool frequencies change because predatory birds (the selective agent) can find and therefore eat light-colored moths. The dark melanic color becomes common among moth populations. This is called **industrial melanism.**

13.11 Check Your Progress How do you know when microevolution has occurred?

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13.12 Both mutations and sexual recombination produce variations

The Hardy-Weinberg principle recognizes mutation as a force that can cause allele frequencies to change in a gene pool and cause microevolution to occur. **Mutations,** which are permanent genetic changes, are the raw material for evolutionary change because, without mutations, there could be no inheritable phenotypic variations among members of a population. The rate of mutations is generally very low—on the order of one per 100,000 cell divisions. Also, it is important to realize that evolution is not goal-oriented, meaning that no mutation arises because the organism "needs" one. For example, the mutation that causes bacteria to be resistant was already present before antibiotics appeared in the environment.

Mutations are the primary source of genetic differences among prokaryotes that reproduce asexually. Generation time is so short that many mutations can occur quickly, even though the rate is low, and since these organisms are haploid, any mutation that results in a phenotypic change is immediately tested by the environment. In diploid organisms, a recessive mutation can remain hidden and become significant only when a homozygous recessive genotype arises. The importance of recessive alleles increases if the environment is changing; it's possible that the homozygous recessive genotype could be helpful in a new environment, if not the present one. It's even possible that natural selection will maintain a recessive allele if the heterozygote has advantages (see Section 13.16).

In sexually reproducing organisms, sexual recombination is just as important as mutation in generating phenotypic differences, because sexual recombination can bring together a new and different combination of alleles. This new combination might produce a more successful phenotype. Success, of course, is judged by the environment and counted by the relative number of healthy offspring an organism produces.

Nonrandom mating and gene flow are possible causes of microevolution, as discussed in Section 13.13.

13.12 Check Your Progress **Would you expect mutations to have helped flowers become adapted to a particular pollinator? Explain.**

13.13 Nonrandom mating and gene flow can contribute to microevolution

Random mating occurs when individuals pair by chance. You make sure random mating occurs when you do a genetic cross on paper or in the lab, and cross all possible types of sperm with all possible types of eggs. **Nonrandom mating** occurs when only certain genotypes or phenotypes mate with one another. **Assortative mating** is a type of nonrandom mating that occurs when individuals mate with those having the *same* phenotype with respect to a certain characteristic. For example, flowers such as the garden pea usually self-pollinate—therefore, the same phenotype has mated with the same phenotype (**Fig. 13.13A**). Assortative mating can also be observed in human society. Men and women tend to marry individuals with characteristics such as intelligence and height that are similar to their own. Assortative mating causes homozygotes for certain gene loci to increase in frequency and heterozygotes for these loci to decrease in frequency.

Gene flow, also called gene migration, is the movement of alleles between populations. When animals move between populations or when pollen is distributed between species (**Fig. 13.13B**), gene flow has occurred. When gene flow brings a new or rare allele into the population, the allele frequency in the next generation changes. When gene flow between adjacent populations is constant, allele frequencies continue to change until an equilibrium is reached. Therefore, continued gene flow tends to make the gene pools similar and reduce the possibility of allele frequency differences between populations.

Genetic drift is another possible cause of microevolution, as discussed in Section 13.14.

13.13 Check Your Progress **Create a scenario in which assortative mating causes flowers to become adapted to their pollinators.**

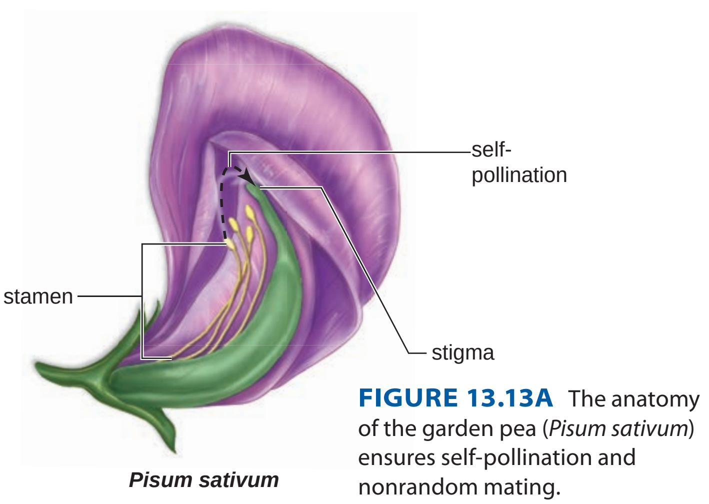

FIGURE 13.13A The anatomy of the garden pea (*Pisum sativum*) ensures self-pollination and nonrandom mating.

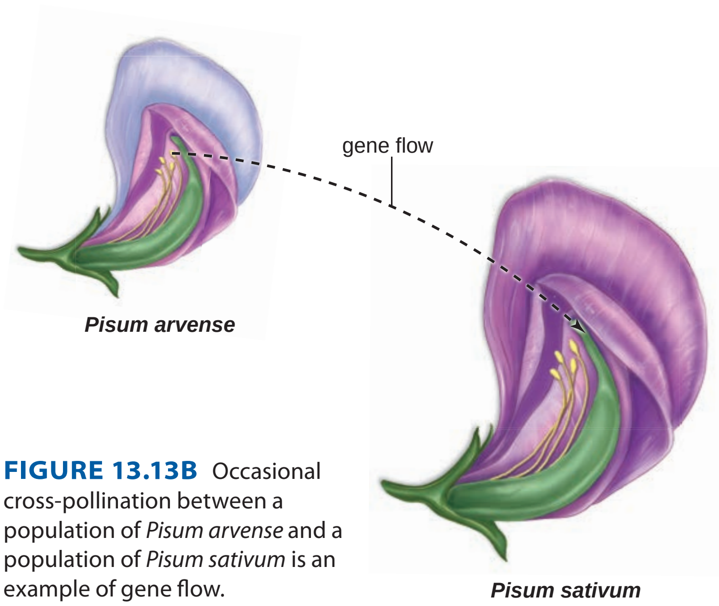

FIGURE 13.13B Occasional cross-pollination between a population of *Pisum arvense* and a population of *Pisum sativum* is an example of gene flow.

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13B Sometimes Mutations Are Beneficial

Imagine trying to redesign a vital mechanical part of an airplane, while still keeping that plane in flight. Sounds nearly impossible, doesn't it? This was one of the puzzles facing early evolutionary biologists. After all, mutations are the main way in which new traits and features arise during evolution, and yet most mutations cause damage. If a feature is important, how can it be altered while still allowing an organism and its offspring to survive?

Geneticists have shown one possible way mutations can accumulate without impairing present function: gene duplication (**Fig. 13B.1**). An extra (and possibly unused) copy of a gene may result from errors during cell division, efforts to repair breakage to DNA, or other mechanisms. The surprising idea here is that these seeming accidents actually can provide raw material for natural selection. Particularly in plants, many examples of gene duplication have been found—for example, the wild mustard plant has undergone at least two duplications of *all* its chromosomes in the past, as well as duplication of several individual genes at various times in history.

An intriguing example of gene duplication involves the sweet-tasting proteins. Of the thousands of proteins studied so far, most have no noticeable flavor—but about half a dozen have an intensely sweet taste. These rare, sweet-tasting proteins are found in plants and plant products from several different continents: The protein "curculin" is found in the fruit of a Malaysian herb (**Fig. 13B.2**); "mabinlin" can be extracted from a traditional Chinese herb; "thaumatin" is found in the fruit of a West African rain forest shrub; and "brazzein" comes from a fruit that grows wild in Gabon, Cameroon, and Zaire. Each of these proteins tastes sweet only to humans and certain monkeys. From the plant's point of view, the proteins likely provided an advantage: Sweeter fruits would be eaten more often and their seeds distributed more widely, ensuring the growth of more plants with genes for making sweet proteins. A question still remains: How did these unusual proteins come about?

No one yet knows exactly how these proteins originated, but gene duplication is a likely answer. The proteins look nothing alike, are found in unrelated plants, and clearly did not come from some ancient shared plant gene. Each protein, however, does resemble other proteins normally found in healthy plants. Brazzein and mabinlin, for example, closely resemble "protein-ase inhibitors," proteins that can help prevent further damage when a plant is injured. Interestingly, however, neither sweet protein has that function. Similar stories are true of most sweet-tasting proteins: They closely resemble other plant proteins with ordinary functions, but the sequences necessary for those other functions seem to be missing or mutated. It's as though pre-existing genes were recycled to become genes for sweet proteins. Presumably a gene duplication in the distant past resulted in an "extra" gene that could mutate freely, while still leaving a "good" copy of the gene to support the plant's functions. In time, the extra copy of the gene acquired mutations that happened to provide a sweet taste, and plants with that mutation gained a special appeal for local diners.

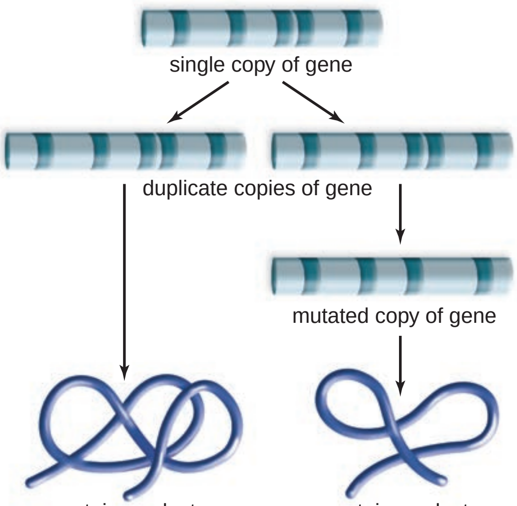

FIGURE 13B.1 Duplication of a gene followed by a mutation in one of the genes is a way for complexity to arise: The new protein might function differently than the original one.

A *Curculigo* plant

The fruits develop at base of leaves.

FIGURE 13B.2 The sweet protein curculin is present in the fruit of a *Curculigo* plant.

FORM YOUR OPINION

1. Humans and perhaps apes and monkeys like sweet foods. How does this benefit plants containing sweet proteins?
2. Are humans influencing the evolution of plants when they propagate them? When they genetically modify them and then propagate them?
3. In what way is artificial selection harmful to the plants and animals selected to reproduce?

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13.14 The effects of genetic drift are unpredictable

Genetic drift refers to changes in the allele frequencies of a gene pool due to chance rather than selection by the environment. Therefore, genetic drift does not necessarily result in adaptation to the environment, as does natural selection. For example, in California, there are a number of cypress groves, each a separate population. The phenotypes within each grove are more similar to one another than they are to the phenotypes in the other groves. Some groves have longitudinally shaped trees, and others have pyramidally shaped trees. The bark is rough in some colonies and smooth in others. The leaves are gray to bright green or bluish, and the cones are small or large. The environmental conditions are similar for all the groves, and no correlation has been found between phenotype and the environment across groves. Therefore, scientists hypothesize that these variations among the groves are due to genetic drift. We know of two mechanisms by which genetic drift could produce phenotypic similarities. They are called the bottleneck effect and the founder effect. Both of these require a very small population.

Small Versus Large Populations Although genetic drift occurs in populations of all sizes, a smaller population is more likely to show the effects of drift. Suppose the allele *B* (for brown) occurs in 10% of the members in a population of frogs. In a population of 50,000 frogs, 5,000 will have the allele *B*. If a hurricane kills off half the frogs, the frequency of allele *B* may very well remain the same among the survivors. On the other hand, 10% of a population with ten frogs means that only one frog has the allele *B*. Under these circumstances, a natural disaster could very well do away with that one frog, should half the population perish. Or, let's suppose that five green frogs out of a ten-member population die. Now the frequency of allele *B* will increase from 10% to 20% (**Fig. 13.14A**).

Bottleneck and Founder Effects When a species is subjected to near extinction because of a natural disaster (e.g., hurricane, earthquake, or fire) or because of overhunting, overharvesting, and habitat loss, it is as if most of the population has stayed behind and only a few survivors have passed through the neck of a bottle. This so-called **bottleneck effect** prevents the majority of genotypes from participating in the production of the next generation. The extreme genetic similarity found in cheetahs is believed to be due to a bottleneck effect. In a study of 47 different enzymes, each of which can have several different forms, the sequence of amino acids in the enzymes was exactly the same in all the cheetahs. What caused the cheetah bottleneck is not known, but today cheetahs suffer from relative infertility because of the intense inbreeding that occurred after the bottleneck. Even if humans were to intervene and the population were to increase in size, the cheetah could still become extinct without genetic variation. Other organisms pushed to the brink of extinction suffer a plight similar to that of the cheetah.

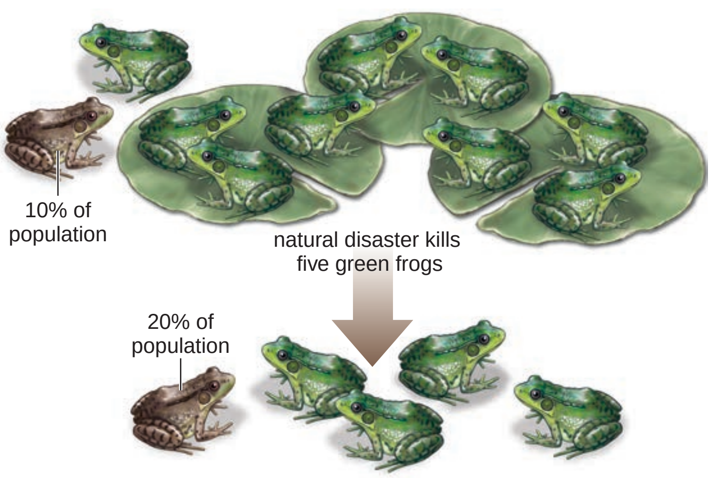

FIGURE 13.14A Chance events can cause allele frequency changes and genetic drift.

FIGURE 13.14B A rare form of dwarfism that is linked to polydactylism is seen among the Amish in Pennsylvania.

The **founder effect** is an example of genetic drift in which rare alleles, or combinations of alleles, occur at a higher frequency in a population isolated from the general population. Founding individuals could contain only a fraction of the total genetic diversity of the original gene pool. Which alleles the founders carry is dictated by chance alone. The Amish of Lancaster County, Pennsylvania, are an isolated group that was begun by German founders. Today, as many as 1 in 14 individuals carries a recessive allele that causes an unusual form of dwarfism (affecting only the lower arms and legs) and polydactylism (extra fingers) (**Fig. 13.14B**). In the general population, only one in 1,000 individuals has this allele.

Natural selection is a possible cause of microevolution, as discussed in Section 13.15.

13.14 Check Your Progress **Could genetic drift have set back the coevolution of flowers and their pollinators? Explain.**

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13.15 Natural selection can be stabilizing, directional, or disruptive

After outlining the process of natural selection earlier in this chapter (see Section 13.3), we now wish to consider natural selection in a genetic context. Many traits are polygenic (controlled by many genes), and the continuous variation in phenotypes results in a bell-shaped curve. The most common phenotype is intermediate between two extremes. When this range of phenotypes is exposed to the environment, natural selection favors the one that is most adaptive under the present environmental circumstances. Natural selection acts much the same way as a governing board that decides which applying students will be admitted to a college. Some students will be favored and allowed to enter, while others will be rejected and not allowed to enter. Of course, in the case of natural selection, the chance to reproduce is the prize awarded. In this context, natural selection can be stabilizing, directional, or disruptive (**Fig. 13.15A**).

Stabilizing selection occurs when an intermediate phenotype is favored (Fig. 13.15A*a*). It can improve adaptation of the population to those aspects of the environment that remain constant. With stabilizing selection, extreme phenotypes are selected against. As an example, consider that when Swiss starlings lay four to five eggs, more young survive than when the female lays more or less than this number. Genes determining physiological characteristics, such as the production of yolk, and behavioral characteristics, such as how long the female will mate, are involved in determining how many eggs are laid.

Human birth weight is another example of stabilizing selection. Through the years, hospital data have shown that human infants born with an intermediate birth weight (3–4 kg) have a better chance of survival than those at either extreme (either

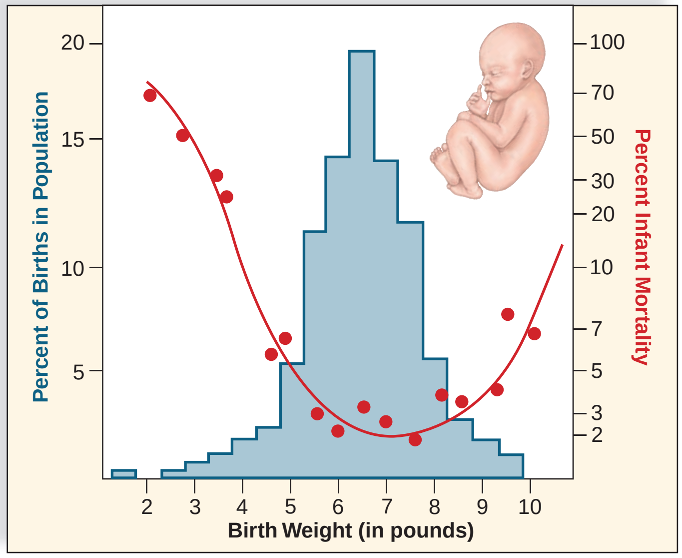

FIGURE 13.15B Stabilizing selection as exemplified by human birth weight.

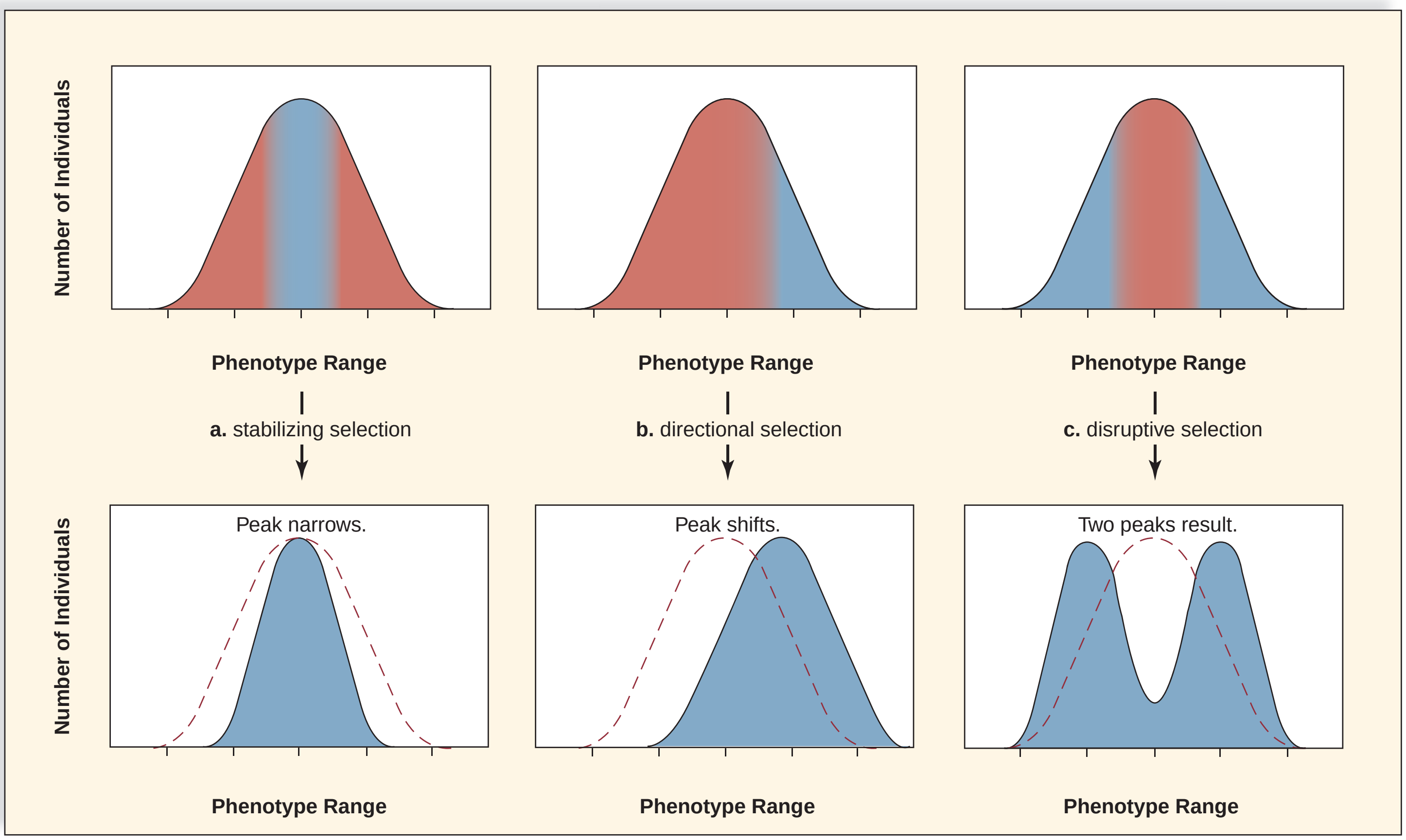

FIGURE 13.15A Phenotype ranges before and after three types of selection. Blue represents favored phenotype(s).

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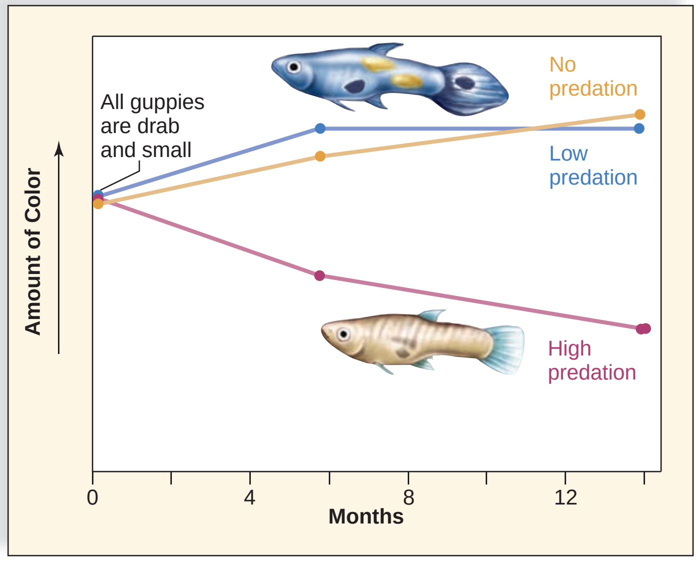
a. Experimental site



b. Result

FIGURE 13.15C Directional selection in guppies.

much less or much greater than usual). When a baby is small, its systems may not be fully functional, and when a baby is large, it may have experienced a difficult delivery. Stabilizing selection reduces the variability in birth weight in human populations (**Fig. 13.15B**).

Directional selection occurs when an extreme phenotype is favored, and the distribution curve shifts in that direction. Such a shift can occur when a population is adapting to a changing environment (Fig. 13.15A*b*).

Two investigators, John Endler and David Reznick, both at the University of California, conducted a study of guppies, which are known for their bright colors and reproductive potential. These investigators noted that on the island of Trinidad, when male guppies are subjected to high predation by other fish, they tend to be drab in color and to mature early and at a smaller size. The drab color and small size are most likely protective against being found and eaten. On the other hand, when male guppies are exposed to minimal or no predation, they tend to be colorful, to mature later, and to attain a larger size.

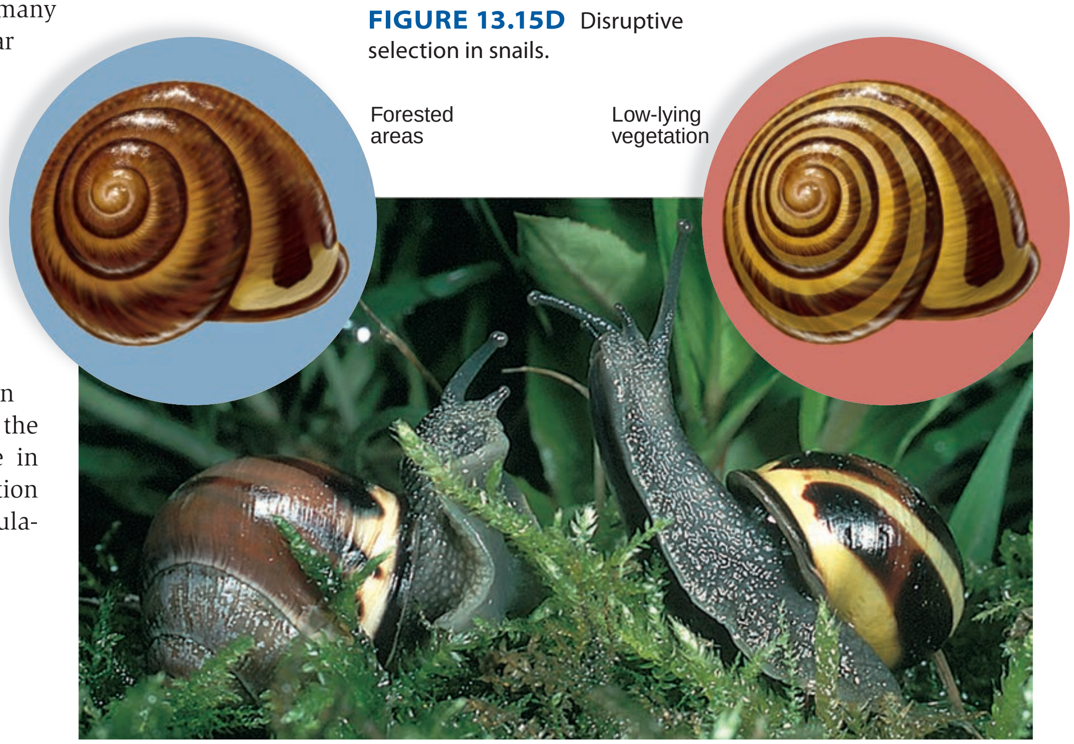
Endler and Reznick performed many experiments, and one set is of particular interest. They took a supply of guppies from a high-predation area (below a waterfall) and placed them in a low-predation area (above a waterfall) (**Fig. 13.15C*a***). The waterfall prevented the predator fish (pike) from entering the low-predation area. They monitored the guppy population for 12 months, and during that year, the guppy population above the waterfall underwent directional selection (Fig. 13.15C*b*). The male members of the population became colorful and large in size. The members of the guppy population below the waterfall (the control population) remained drab and small.

In **disruptive selection,** two or more extreme phenotypes are favored over any intermediate phenotype (Fig. 13.15A*c*, *right*). For example, British land snails (*Cepaea nemoralis*) have a wide habitat range that includes low-vegetation areas (grass fields and hedgerows) and forests. In forested areas, thrushes feed mainly on light-banded snails, and the snails with dark shells become more prevalent. In low-vegetation areas, thrushes feed mainly on snails with dark shells, and light-banded snails become more prevalent. Therefore, these two distinctly different phenotypes are found in the population (**Fig. 13.15D**).

Stabilizing selection, discussed in Section 13.16, maintains the heterozygote, especially if it has an advantage over the homozygote, as seen in sickle-cell disease.

13.15 Check Your Progress **If the flowers of a species are presently only one color and the pollinator prefers this color, is stabilizing selection occurring? Explain.**

FIGURE 13.15D Disruptive selection in snails.



13.16 Stabilizing selection can help maintain the heterozygote

Variations are maintained in a population for any number of reasons. Mutation still creates new alleles, and recombination still recombines these alleles during gametogenesis and fertilization. Gene flow might still occur. If the receiving population is small and mostly homozygous, gene flow can be a significant source of new alleles. Genetic drift also occurs, particularly in small populations, and the end result may be contrary to adaptation to the environment. Natural selection never starts from scratch and therefore the result is often a compromise. An erect posture freed the hands of humans but subjected the spine to injury because it is imperfectly adapted. But the benefit of freeing the hands must have been worth the risk of spinal injuries or it would not have evolved. An inefficient selective agent can play a role in maintaining diversity; predatory birds never catch all the white moths when pollutants darken the vegetation. A changing environment retains the ability of the medium ground finch on the Galapagos island to change its beak size as appropriate to the food supply. Clearly, the maintenance of variation among a population has survival value for the species. Here, we consider that heterozygote superiority in a particular environment can assist the maintenance of genetic, and therefore phenotypic, variations in future generations.

Sickle-cell Disease Sickle-cell disease can be a devastating condition. Patients may have severe anemia, physical weakness, poor circulation, impaired mental function, pain and high fever, rheumatism, paralysis, spleen damage, low resistance to disease, and kidney and heart failure. In these individuals, the red blood cells are sickle-shaped and tend to pile up and block flow through tiny capillaries. The condition is due to an abnormal form of hemoglobin (*Hb*), the molecule that carries oxygen in red blood cells. People with sickle-cell disease (Hb^SHb^S) tend to die early and leave few offspring, due to hemorrhaging and organ destruction. Interestingly, however, geneticists studying the distribution of sickle-cell disease in Africa have found that the recessive allele (Hb^S) has a higher frequency in regions (purple color) where the disease malaria is also prevalent (**Fig. 13.16**). Malaria is caused by a protozoan parasite that lives in and destroys the red blood cells of the normal homozygote (Hb^AHb^A). Individuals with this genotype have fewer offspring, due to an early death or to debilitation caused by malaria.

People who are heterozygous (Hb^AHb^S) have an advantage over both homozygous genotypes because they don't die from sickle-cell disease and they don't die from malaria. The parasite causes any red blood cell it infects in these individuals to become sickle-shaped. Sickle-shaped red blood cells lose potassium, and this causes the parasite to die. **Heterozygote advantage** causes all three alleles to be maintained in the population. It's as if natural selection were a store owner balancing the advantages and disadvantages of maintaining the recessive allele Hb^S in the warehouse. As long as the protozoan that causes malaria is present in the environment, it is advantageous to maintain the recessive allele, as shown in the following table:

Genotype	Phenotype	Result
Hb^AHb^A	Normal	Dies due to malarial infection
Hb^AHb^S	Sickle-cell trait	Lives due to protection from both
Hb^SHb^S	Sickle-cell disease	Dies due to sickle-cell disease

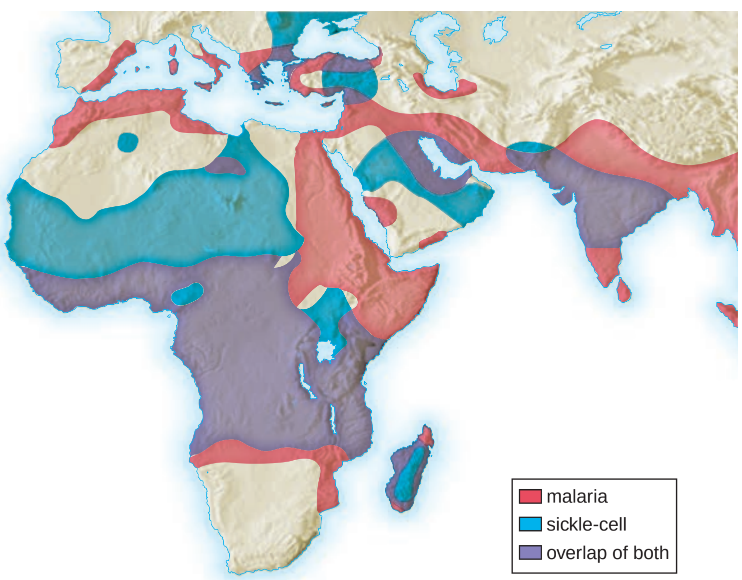


FIGURE 13.16 Sickle-cell disease is more prevalent in areas of Africa where malaria is more common.

Heterozygote advantage is also an example of stabilizing selection because the genotype Hb^AHb^S is favored over the two extreme genotypes, Hb^AHb^A and Hb^SHb^S. In the parts of Africa where malaria is common, one in five individuals is heterozygous (has sickle-cell trait) and survives malaria, while only 1 in 100 is homozygous, Hb^SHb^S, and dies of sickle-cell disease.

What happens in the United States where malaria is not prevalent? As you would expect, the frequency of the Hb^S allele is declining among African Americans because the heterozygote has no particular advantage in this country.

Cystic Fibrosis Stabilizing selection is also thought to have influenced the frequency of other alleles. Cystic fibrosis is a debilitating condition that leads to lung infections and digestive difficulties. In this instance, the recessive allele, common among individuals of northwestern European descent, causes the person to have a defective plasma membrane protein. The agent that causes typhoid fever can use the normal version of this protein, but not the defective one, to enter cells. Here again, heterozygote superiority caused the recessive allele to be maintained in the population.

13.16 Check Your Progress **Could heterozygote advantage be used to show that natural selection does not always favor the dominant genotype?**

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THE CHAPTER IN REVIEW

SUMMARY

Darwin Developed a Natural Selection Hypothesis

13.1 Darwin made a trip around the world

- Cuvier founded the science of **paleontology** and said that catastrophes cause evolution to occur.
- Lamarck proposed the inheritance of acquired characteristics as a mechanism of evolution.
- On his trip around the world, Darwin observed that species change from place to place and through time.
- In his book Lyell explained how fossils come to be in **strata** and suggested the idea of **uniformitarianism** (geologic changes occur at a uniform rate). The book and his observations of fossils convinced Darwin that the Earth had existed long enough for evolution to have occurred.

13.2 Artificial selection mimics natural selection

- In **artificial selection,** humans (not the environment) select certain characteristics to perpetuate.

13.3 Darwin formulated natural selection as a mechanism for evolution

- During **natural selection,** an environmental **selective agent** selects which organisms will reproduce.
- Natural selection has several components:
  - The members of a population have inheritable variations.
  - A population is able to produce more offspring than the environment can support.
  - Certain members of a population survive and reproduce more than other members because they have an advantage suited to the environment.
  - Natural selection results in a population adapted to its environment.
- **Evolution** can be defined as changes in a population over time due to an accumulation of inherited differences.

13.4 Wallace independently formulated a natural selection hypothesis

- Wallace was a naturalist who had also read Malthus and arrived at conclusions similar to those of Darwin.

The Evidence for Evolution Is Strong

13.5 Fossils provide a record of the past

- **Fossils** are hard parts of organisms or other traces of life found in sedimentary rock.
- **Paleontologists** find and study fossils.
- The **fossil record** indicates that life has progressed from simple to complex.

13.6 Fossils are evidence for common descent

- During evolution, organisms share **common ancestors** just as you and your cousins share grandparents.
- **Transitional fossils** have the characteristics of two different groups and thus provide clues to the evolutionary relationships between organisms.

13.7 Anatomic evidence supports common descent

- **Homologous structures** are anatomical similarities due to common ancestry.
- **Analogous structures** have the same functions in different organisms but are not anatomically similar.

- Only homologous structures (not analogous structures) indicate that organisms have a *recent* common ancestor.
- Organisms have **vestigial structures** despite their being reduced and nonfunctional because they were once functional in an ancestor.
- All vertebrates share the same embryonic features but they are later modified for different purposes.

13.8 Biogeographic evidence supports common descent

- **Biogeography** is the study of the distribution of organisms around the globe.
- Plants and animals evolved in particular locations, and therefore widely separated similar environments contain different but similarly adapted organisms.

13.9 Molecular evidence supports common descent

- The degree of similarity of DNA base sequences or amino acid sequences shows a pattern of relatedness consistent with fossil record data.

Population Genetics Tells Us When Microevolution Occurs

13.10 The human population is diverse

- **Microevolution** refers to genetic changes below the species level.
- A **population** is composed of all the members of a species in a particular locale at the same time.
- The existence of **SNPs (single nucleotide polymorphisms)** reveals the genetic diversity of humans.

13.11 A Hardy-Weinberg equilibrium is not expected

- Microevolution is evidenced by changes in **gene pool** allele frequencies.
- Hardy and Weinberg showed that it was possible to calculate the genotype and allele frequencies of a population by using the following equation:

$$p^2 + 2pq + q^2 = 1$$

- This equation predicts a Hardy-Weinberg equilibrium. The **Hardy-Weinberg principle** states that microevolution does not occur as long as mutations, gene flow, nonrandom matings, genetic drift, and natural selection do not occur.
- Generally, allele frequencies do change between generations, and microevolution does occur. For example, dark moths become prevalent in moth populations when trees become dark due to pollution. This is called **industrial melanism.**

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13.12 Both mutations and sexual recombination produce variations

- **Mutations** are the primary source of genetic differences in prokaryotes.
- Sexual recombination and mutations are equally important in eukaryotes.

13.13 Nonrandom mating and gene flow can contribute to microevolution

- **Nonrandom mating** occurs when only certain genotypes or phenotypes mate with one another.
- **Assortative mating** is a type of nonrandom mating in which individuals mate with those that have the same phenotype for a particular characteristic.
- **Gene flow** results when alleles move between populations due to migration.

13.14 The effects of genetic drift are unpredictable

- **Genetic drift** refers to changes in allele frequency in a gene pool due to chance.
- The **bottleneck effect** prevents the majority of genotypes from participating in production of the next generation.
- The **founder effect** occurs when rare alleles contributed by the founders of a population occur at a higher frequency in isolated populations.

13.15 Natural selection can be stabilizing, directional, or disruptive

- In **stabilizing selection,** extreme phenotypes are selected against while intermediate phenotypes are favored.
- In **directional selection,** an extreme phenotype is favored.
- In **disruptive selection,** two or more extreme phenotypes are favored over the intermediate phenotype.

13.16 Stabilizing selection can help maintain the heterozygote

- **Heterozygote advantage** causes the sickle-cell allele to be maintained in Africa, even though the homozygous recessive is lethal because the heterozygote is protective against malaria.
- The recessive allele for cystic fibrosis is believed to have been maintained because a faulty membrane protein doesn't allow the typhoid bacterium to enter cells.

TESTING YOURSELF

Darwin Developed a Natural Selection Hypothesis

1. Why was it helpful to Darwin to learn that Lyell had concluded the Earth was very old?
   a. An old Earth has more fossils than a new Earth.
   b. It meant there was enough time for evolution to have occurred slowly.
   c. It meant there was enough time for the same species to spread into all continents.
   d. Darwin said artificial selection occurs slowly.
   e. All of these are correct.
2. Which of these pairs is mismatched?
   a. Charles Darwin—natural selection
   b. Cuvier—series of catastrophes explains the fossil record
   c. Lamarck—uniformitarianism
   d. All of these are correct.
3. Which is most likely to be favored during natural selection, but not artificial selection?
   a. fast seed germination rate
   b. short generation time
   c. efficient seed dispersal
   d. lean pork meat production
4. Which of these is/are necessary to natural selection?
   a. variations
   b. differential reproduction
   c. inheritance of differences
   d. All of these are correct.
5. Natural selection is the only process that results in
   a. genetic variation.
   b. adaptation to the environment.
   c. phenotypic change.
   d. competition among individuals in a population.
6. **THINKING CONCEPTUALLY** The adaptive results of natural selection cannot be determined ahead of time. Explain.

The Evidence for Evolution Is Strong

7. The fossil record offers direct evidence for common descent because you can
   a. see that the types of fossils change over time.
   b. sometimes find common ancestors.
   c. trace the ancestry of a particular group.
   d. trace the biological history of living things.
   e. All of these are correct.
8. Which of the following is not an example of a vestigial structure?
   a. human tailbone　　c. pelvic girdle in snakes
   b. ostrich wings　　d. dog kidney
9. If evolution occurs, we would expect different biogeographic regions with similar environments to
   a. all contain the same mix of plants and animals.
   b. each have its own specific mix of plants and animals.
   c. have plants and animals with similar adaptations.
   d. have plants and animals with different adaptations.
   e. Both b and c are correct.
10. DNA nucleotide differences between organisms
    a. indicate how closely related organisms are.
    b. indicate that evolution occurs.
    c. explain why there are phenotypic differences.
    d. are to be expected.
    e. All of these are correct.

For questions 11–14, match the evolutionary evidence in the key to the description. Choose more than one answer if correct.

KEY:

a. biogeographic evidence　　c. molecular evidence
b. fossil evidence　　d. anatomic evidence

11. Islands have many unique species not found elsewhere.
12. All vertebrate embryos have pharyngeal pouches.
13. Distantly related species have more amino acid differences in cytochrome *c*.
14. Transitional links have been found between major groups of animals.
15. **THINKING CONCEPTUALLY** Why can researchers make decisions about who is related to whom using only DNA base sequence data? (See Section 13.9.)

Population Genetics Tells Us When Microevolution Occurs

For questions 16 and 17, consider that about 75% of white North Americans can taste the chemical phenylthiocarbamide. The ability

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to taste is due to the dominant allele *T*. Nontasters are *tt*. Assume this population is in Hardy-Weinberg equilibrium.

16. What is the frequency of *t*?
    a. 0.25
    b. 0.70
    c. 0.55
    d. 0.09
    e. 0.60
17. What is the frequency of heterozygous tasters?
    a. 0.50
    b. 0.21
    c. 0.2475
    d. 0.45
18. The offspring of better-adapted individuals are expected to make up a larger proportion of the next generation. The most likely explanation is
    a. mutations and nonrandom mating.
    b. gene flow and genetic drift.
    c. mutations and natural selection.
    d. mutations and genetic drift.
19. The Northern elephant seal went through a severe population decline as a result of hunting in the late 1800s. The population has rebounded but is now homozygous for nearly every gene studied. This is an example of
    a. negative assortative mating.
    b. migration.
    c. mutation.
    d. a bottleneck.
    e. disruptive selection.
20. When a population is small, there is a greater chance of
    a. gene flow.
    b. genetic drift.
    c. natural selection.
    d. mutations occurring.
    e. sexual selection.

THINKING SCIENTIFICALLY

1. You decide to repeat the guppy experiment described in Section 13.15 because you want to determine what genotype changes account for the results. What might you do to detect such changes?
2. A cotton farmer applied a new pesticide against the boll weevil for several years. At first, the treatment was successful, but then the insecticide became ineffective and the boll weevil rebounded. Did evolution occur? Explain.

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CONNECTING THE CONCEPTS

Darwin took a trip around the world as the naturalist aboard the HMS *Beagle*. During his trip, he collected fossils and made several observations that made him think evolution occurs. Darwin was aware of artificial selection, and he had read an essay by Malthus suggesting that the members of a population compete with one another for resources. Darwin began to see that a competitive edge would allow certain members of a population to survive and reproduce more than other members of the population. Assuming that advantageous traits are inheritable, future generations would eventually acquire adaptations to the local environment. Darwin called this process, by which a population adapts to its environment, natural selection because nature selects which members of a population will reproduce to a greater extent. Natural selection is like artificial selection except the environment instead of a breeder selects which plants or animals will reproduce.

Evolution explains the unity and diversity of life. Life is unified because of common descent, and it is diverse because of adaptations to particular environments. Darwin used the expression "descent with modification" to explain evolution. Support for common descent includes transitional fossils, anatomic features (homologous structures, vestigial structures, and embryologic similarities), biogeographic data, and molecular evidence.

In the 1930s, biologists developed a way to apply the principles of genetics to evolution. Populations would be in a Hardy-Weinberg equilibrium (allele frequencies stay the same) if mutation, gene flow, nonrandom mating, genetic drift, and natural selection did not occur. However, these events do occur, and they are the agents of evolutionary change that lead to microevolution, recognizable by allele frequency changes. Mutations provide the raw material for evolution. Genetic drift results in allele frequency changes due to a chance event, as when only a few members of a population are able to reproduce because of a natural disaster or because they have founded a colony. Natural selection is the only agent of evolution that results in adaptation to the environment.

Chapter 14 concerns macroevolution, the manner in which new species arise. The origin of new species is essential to the history of life on Earth, which we consider in Chapter 15.

PUT THE PIECES TOGETHER

1. We now know that evolution by natural selection can be observed over a short period of time (years, months). Give examples.
2. Why would you expect evolution to have a genetic basis? Use industrial melanism to support the genetic basis of evolution.
3. Why would it be *incorrect* to say that bacteria became resistant in order to escape being killed by antibiotics?

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14

Speciation and Evolution

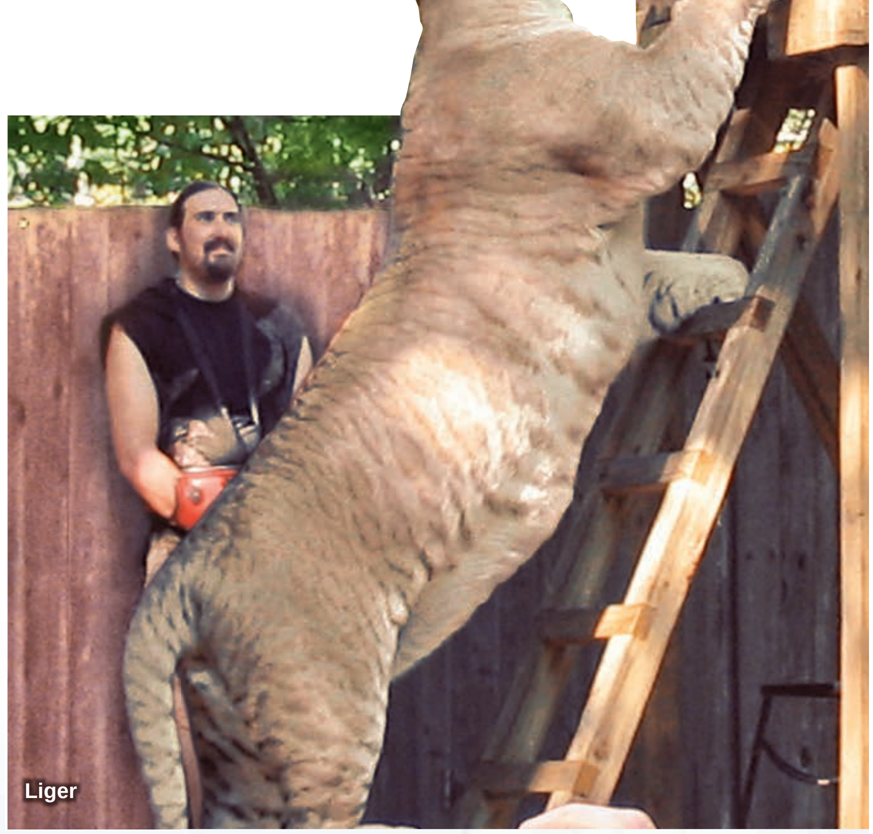
CHAPTER OUTLINE

APPLICATIONS

Hybrid Animals Do Exist

The immense liger, an offspring of a lion father and a tiger mother, really impressed Brian. Upon returning from the show, he immediately began researching more information. To his surprise, he found that ligers are one of many hybridized species that have been recorded. His search led him to common hybrid websites that discussed mules, zorses, zonkeys, and beefalos. He also discovered several strange hybrids, such as the wolphin, a cross between a false killer whale and a dolphin; a grolar, a cross between a grizzly bear and a polar bear; and a cama, a cross between a camel and a llama. Usually, in naming hybrids, the name of the male parent is used first. Thus, a zorse has a zebra father and a horse mother.

A hybrid results from breeding two closely related, but distinct, species. Lions and tigers meet this criterion, but a hybrid between a cat and a rabbit would not exist because these animals are not closely related. Hybrids are usually the result of human activities, either by direct intervention or by placing related species in the same setting. For example, humans have mated female donkeys and male horses to develop mules for centuries. The vast majority of hybrids have been born in zoos as a



Liger

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result of bringing together related species from different continents. Afterall, lions live in Africa and tigers live in Asia. Therefore, most ligers are born in captivity. Reports of ligers in zoos can be traced back to the early 1800s.

Brian found that ligers are much larger than their parental stock. In fact, they are the largest felines in the world, measuring up to 12 feet tall when standing on their hind legs and weighing as much as 1,000 pounds. Their coat color is usually tan with tiger stripes on the back and hindquarters and lion cub spots on the abdomen. A liger can produce both the "chuff" sound of a tiger and the roar of a lion. Male ligers may have a modest lion mane or no mane at all. Most ligers have an affinity for water and love to swim. Generally, ligers have a gentle disposition; however, considering their size and heritage, handlers should be extremely careful. Brian also discovered tigons, rare animals that have a tiger father and a lion mother. Generally, tigons are smaller than their parental stock.

Most hybrids are sterile. Mules inherit an uneven number of chromosomes that cannot pair up during meiosis, making it rarely possible for them to form gametes. Ligers have an even number of chromosomes but males are infertile presumedly because the pairing of the Y from a lion and the X from the tiger is impossible during meiosis. Female ligers are fertile and in recent years, Li-ligers (both parents are ligers), Li-tigons (father is a liger, mother is a tigon), Ti-ligers (father is a tiger, mother is a liger), and Ti-tigons (father is a tiger, mother is a tigon) have been produced. These unusual hybrids display a variety of lion and tiger traits.

This chapter is about speciation, the origin of species. Without the origin of new species there would have been no history of life on Earth. In this chapter we will see how speciation occurs and how it may be observed during present times and in the fossil record.


Tigon


Mules


Zorse

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Evolution of Diversity Requires Speciation

Learning Outcomes

- Compare and contrast the evolutionary species concept with the biological species concept. (14.1)
- List and give examples of five prezygotic isolating mechanisms and three postzygotic isolating mechanisms. (14.2)

Macroevolution is the evolution of species. A species can be defined using the evolutionary species or the biological species concept. In order for a species to be biologically distinct, reproductive barriers are needed to maintain its genetic differences from other species. These barriers consist of prezygotic and postzygotic isolating mechanisms.

14.1 Species have been defined in more than one way

In Chapter 13, we concluded that **microevolution** was any allele frequency change within the gene pool of a population. Macroevolution, which is observed best within the fossil record, requires the origin of species, also called speciation. **Speciation** is the splitting of one species into two or more species, or the transformation of one species into a new species over time. Speciation is the final result of changes in gene pool allele and genotype frequencies. The diversity of life we see about us is absolutely dependent on speciation, so it is important to be able to define a species and to know when speciation has occurred. In Chapter 1 we defined a species as a type of living thing, but now we want to characterize a species in more depth.

The **evolutionary species concept** recognizes that every species has its own evolutionary history, at least part of which is in the fossil record. As an example, consider that the species depicted in **Figure 14.1A** are a part of the evolutionary history of toothed whales. Binomial nomenclature, discussed in Section 1.5, was used to name these ancestors of killer whales as well as the other species of toothed whales living today. The two-part scientific name when translated from the Latin often tells you something about the organism. For example, the scientific name of the dinosaur *Tyrannosaurus rex* means "tyrant-lizard king."

The evolutionary species concept relies on traits, called diagnostic traits, to distinguish one species from another. As long as these traits are the same, fossils are considered members of the same species. Abrupt changes in these traits indicate the evolution of a new species in the fossil record. In summary, the evolutionary species concept states that members of a species share the same distinct evolutionary pathway and that species can be recognized by diagnostic trait differences.

One advantage of the evolutionary species concept is that it applies to both sexually and asexually reproducing organisms. However, a major disadvantage can occur when anatomic traits are used to distinguish species. The presence of variations, such as size differences in male and female animals, might make you think you are dealing with two species instead of one, and the lack of distinct differences could cause you to conclude that two fossils are the same species when they are not.

The evolutionary species concept necessarily assumes that the members of a species are reproductively isolated. If members of different species were to reproduce with one another, their evolutionary history would be mingled, not separate. By contrast, the **biological species concept** relies primarily on reproductive isolation rather than trait differences to define a species. In other words, although traits can help us

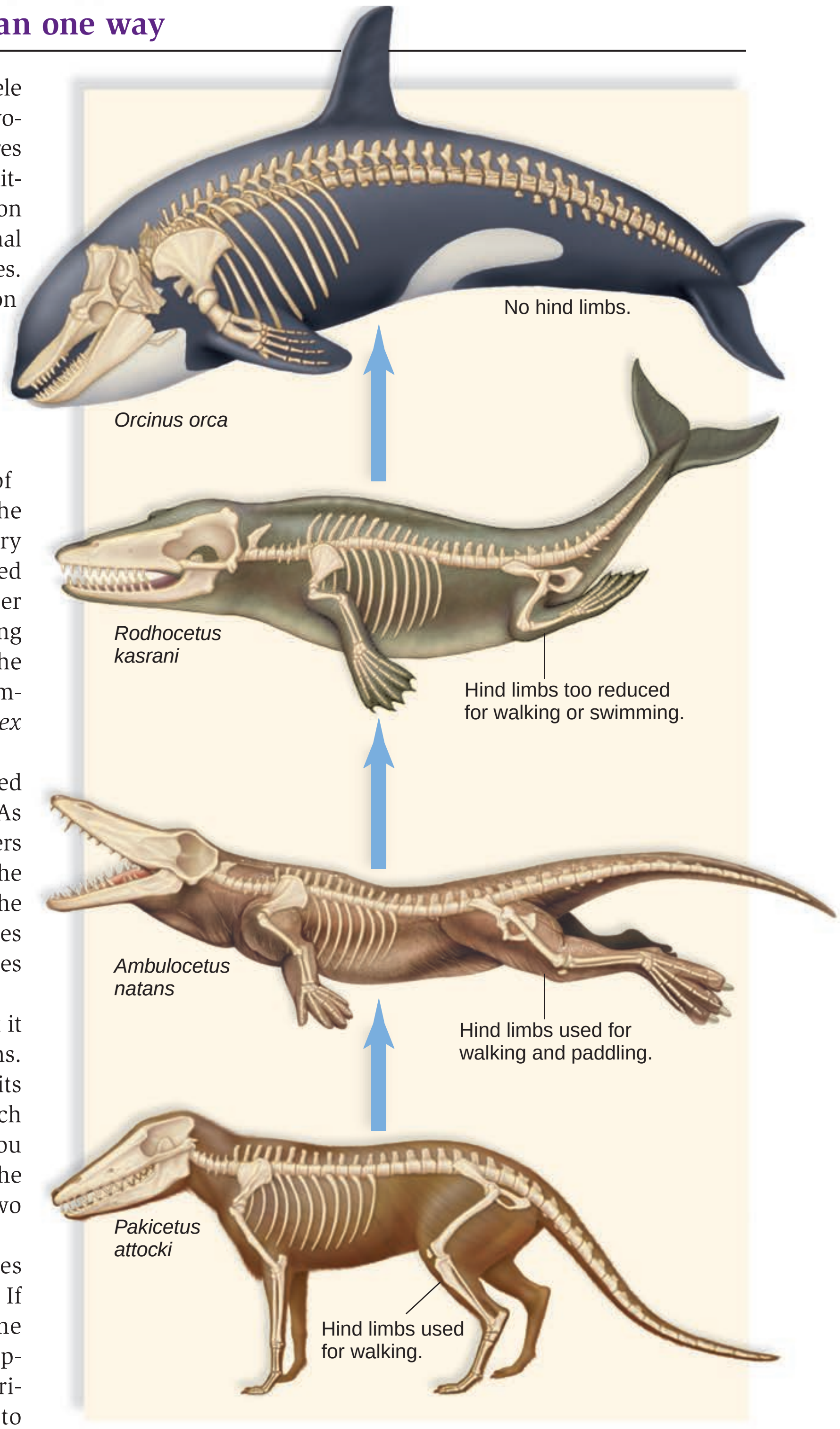

FIGURE 14.1A Evolution of the modern toothed whale.

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Acadian flycatcher, *Empidonax virescens*

Willow flycatcher, *Empidonax traillii*

Least flycatcher, *Empidonax minimus*

FIGURE 14.1B Three species of flycatchers. The call of each bird is given on the photograph.

distinguish species, the most important criterion, according to the biological species concept, is reproductive isolation—the members of a species have a single gene pool. While useful, the biological species concept cannot be applied to asexually reproducing organisms, to organisms known only by the fossil record, or to species that interbred when they lived near one another. The benefit of the concept is that it can designate species even when trait differences may be difficult to find. The flycatchers in **Figure 14.1B** are very similar, but they do not reproduce with one another; therefore, they are separate species. They live in different habitats. The Acadian flycatcher inhabits deciduous forests and wooded swamps, especially beeches; the willow flycatcher inhabits thickets, bushy pastures, old orchards, and willows; and the least flycatcher inhabits open woods, orchards, and farms. They also have different calls. Conversely, when anatomic differences are apparent, but reproduction is not deterred, only one species is present. Despite noticeable variations, humans from all over the world can reproduce with one another and belong to one species. The Massai of East Africa and the Eskimos of Alaska are kept apart by geography, but we know that, should they meet, reproduction between male and female would be possible (**Fig. 14.1C**).

The biological species concept gives us a way to know when speciation has occurred, without regard to anatomic differences. As soon as descendants of a group of organisms are able to reproduce only among themselves, speciation has occurred.

In recent years, the biological species concept has been supplemented by our knowledge of molecular genetics. DNA base sequence data and differences in proteins can indicate the relatedness of groups of organisms but it can't indicate when speciation has occurred. Macroevolution starts with speciation but anatomic data such as the differences in the whales in Figure 14.1A play a prominent role in deciphering the history of life.

FIGURE 14.1C The Massai of East Africa (*left*) and the Eskimos of Alaska (*right*) belong to the same species.

14.1 Check Your Progress **Should hybrid animals such as ligers be given their own scientific name and considered a separate species? Explain.**

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14.2 Reproductive barriers maintain genetic differences between species

As mentioned in the previous section, for two species to be separate, they must be reproductively isolated—that is, gene flow must not occur between them. Isolating mechanisms that prevent successful reproduction from occurring are reproductive barriers (**Fig. 14.2A**). In evolution, reproduction is successful only when it produces fertile offspring.

Prezygotic (before the formation of a zygote) **isolating mechanisms** are those that prevent reproductive attempts and make it unlikely that fertilization will be successful if mating is attempted. Scientists have identified several types of isolation that make it highly unlikely for particular genotypes to contribute to a population's gene pool:

Habitat isolation When two species occupy different habitats, even within the same geographic range, they are less likely to meet and attempt to reproduce. This is one of the reasons that the flycatchers in Figure 14.1B do not mate, and that red maple and sugar maple trees do not exchange pollen. In tropical rain forests, many animal species are restricted to a particular level of the forest canopy, and in this way they are isolated from similar species.

Temporal isolation Several related species can live in the same locale, but if each reproduces at a different time of year, they do not attempt to mate. Five species of frogs of the genus *Rana* are all found at Ithaca, New York. The species remain separate because the period of most active mating is different for each (**Fig. 14.2B**), and because whenever there is an overlap, different breeding sites are used. For example, wood frogs breed in woodland ponds or shallow water, leopard frogs in lowland swamps, and pickerel frogs in streams and ponds on high ground.

Behavioral isolation Many animal species have courtship patterns that allow males and females to recognize one another. The male blue-footed boobie in **Figure 14.2C** does a dance unique to the species. Male fireflies are recognized by females of their species by the pattern of their flashings; similarly, female crickets recognize male crickets by their chirping. Many males recognize females of their species by sensing chemical signals called pheromones. For example, female gypsy moths have special abdominal glands from which they secrete pheromones (see Section 27.3, p. 552) that are detected downwind by receptors on the antennae of males.

Mechanical isolation Inaccessibility of pollen to certain pollinators can prevent cross-fertilization in plants, and the sexes of many insect species have genitalia that do not match. When animal genitalia or plant floral structures are incompatible, reproduction cannot occur. Other characteristics can also make mating impossible. For example, male dragonflies have claspers that are suitable for holding only the females of their own species.

Gamete isolation Even if the gametes of two different species meet, they may not fuse to become a zygote. In animals, the

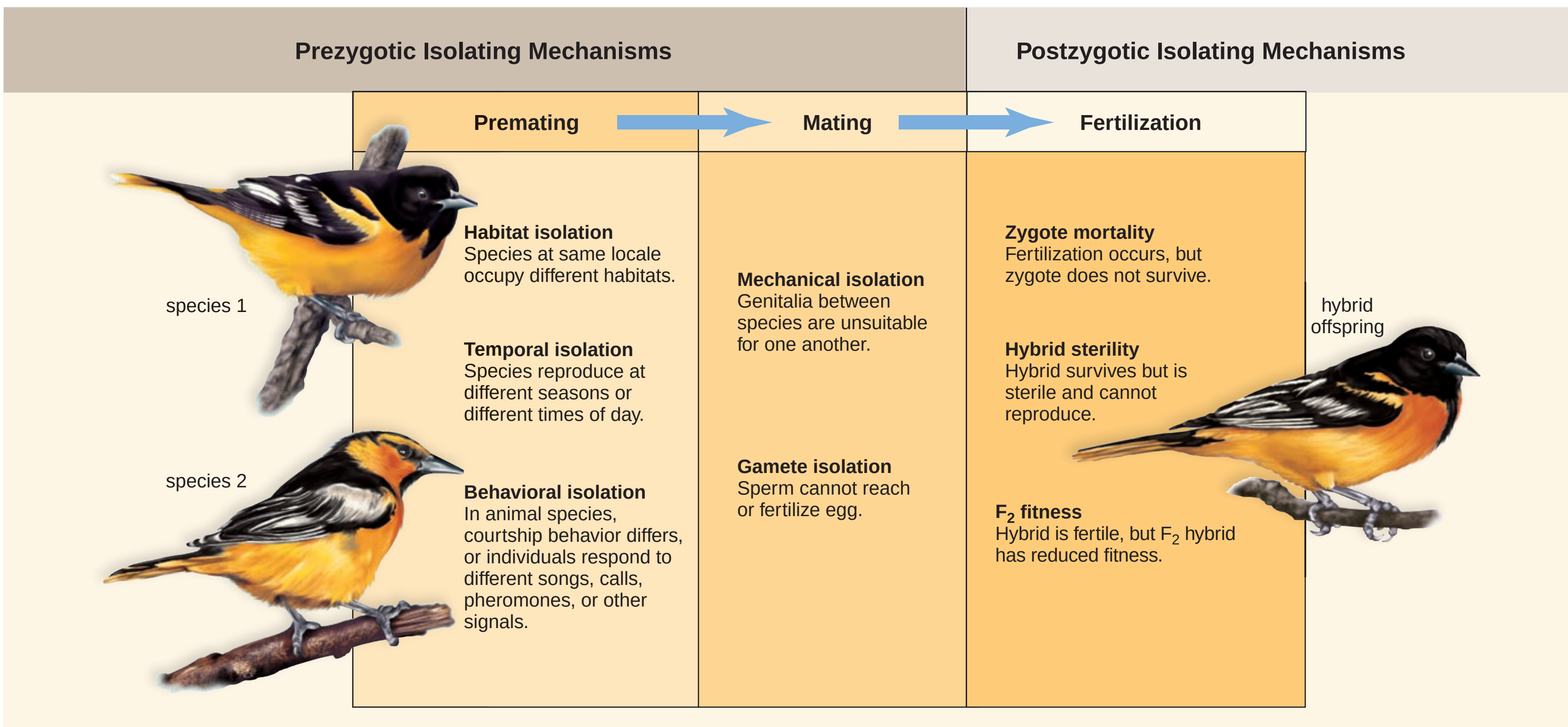

FIGURE 14.2A Reproductive barriers.

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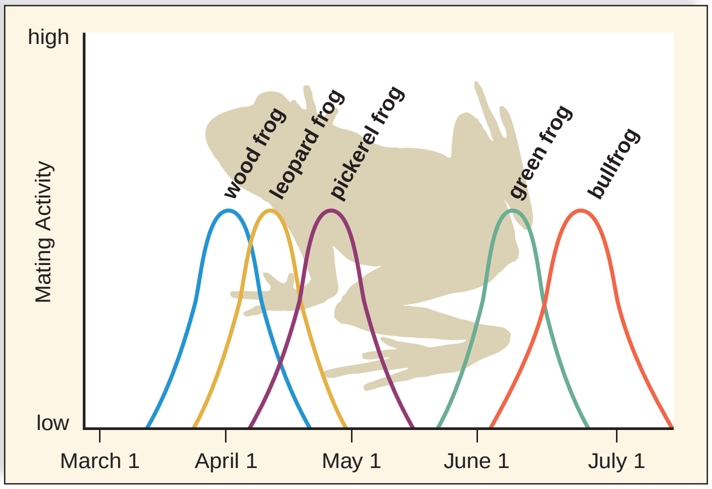

FIGURE 14.2B Mating activity peaks at different times of the year for these species of frogs.

sperm of one species may not be able to survive in the reproductive tract of another species, or the egg may have receptors only for sperm of its species. In plants, pollen grains are species-specific and will not form a pollen tube for another species. Without a pollen tube, the sperm cannot successfully reach the egg.

Postzygotic (after the formation of a zygote) **isolating mechanisms** prevent hybrid offspring from developing or breeding, even if reproduction attempts have been successful.

Zygote mortality A hybrid zygote may not be viable, and so it dies. A zygote with two different chromosome sets may fail to go through mitosis properly, or the developing embryo may receive incompatible instructions from the maternal and paternal genes so that it cannot continue to exist.

Hybrid sterility The hybrid zygote may develop into a sterile adult. As is well known, a cross between a male horse and a female donkey produces a mule, which is usually sterile—it cannot reproduce (**Fig. 14.2D**). Sterility of hybrids generally results from complications in meiosis that lead to an inability to produce viable gametes. A cross between a cabbage and a radish produces offspring that cannot form gametes, most likely because the cabbage chromosomes and the radish chromosomes cannot align during meiosis (see Section 14.5).

F_2 fitness Even if hybrids can reproduce, their offspring may be unable to reproduce. In some cases, mules are fertile, but their offspring (the F_2 generation) are not fertile.

Having discussed how to define a species and what keeps them separate, we will discuss in Section 14.3 how species generally arise.

14.2 Check Your Progress *a.* Which of the prezygotic isolating mechanisms apparently keeps lions and tigers from mating in the wild? Explain. *b.* Which of the postzygotic isolating mechanisms is still working to a degree to keep lions and tigers separate species? Explain.

FIGURE 14.2C Male blue-footed boobie doing a courtship dance for a female.

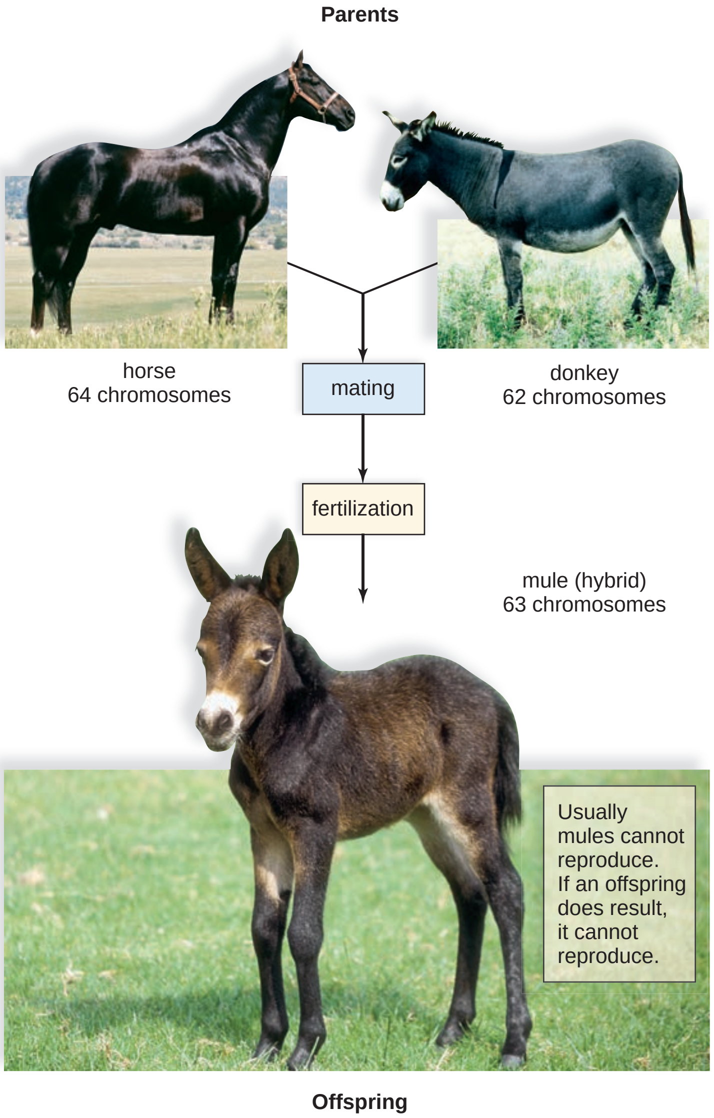

FIGURE 14.2D Mules cannot reproduce due to chromosome incompatibility.

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Origin of Species Usually Requires Geographic Separation

Learning Outcomes

- Describe and give examples of allopatric speciation. (14.3)
- Describe and give examples of adaptive radiation. (14.4)

Geographic isolation fosters the genetic changes that result in allopatric speciation. Modern-day examples of allopatric speciation include the evolution of distinct forms of *Ensatina* salamanders in California. Adaptive radiation occurs when an ancestral species evolves into several new and different species, each adapted to a different environment. The evolution of a wide variety of honeycreepers on the Hawaiian Islands is an example of adaptive radiation.

14.3 Allopatric speciation utilizes a geographic barrier

In 1942, Ernst Mayr, an evolutionary biologist, published the book *Systematics and the Origin of Species,* in which he proposed the biological species concept and this process by which speciation could occur:

- Two subpopulations of a species are experiencing gene flow and therefore have a single gene pool.
- A geographic barrier appears and prevents any further gene flow between the two populations.
- Genetic drift and different selection pressures cause divergence between the isolated gene pools.
- Reproductive isolation has occurred and continues even when the geographic barrier is removed.
- Speciation is now complete and two separate species exist.

This process is termed **allopatric speciation** (allopatric means "different country") because it requires that the subpopulations be separated by a geographic barrier.

***Ensatina* Salamanders** Much data in support of allopatric speciation have since been discovered. **Figure 14.3A** features an example of allopatric speciation that has been extensively studied in California. An ancestral population of *Ensatina* salamanders lives in the Pacific Northwest. 1 Members of this ancestral population migrated southward, establishing a series of subpopulations. Each subpopulation was exposed to its own selective pressures along the coastal mountains and the Sierra Nevada mountains. 2 Due to the presence of the Central Valley of California, gene flow rarely occurs between the eastern populations and the western populations. 3 Genetic differences increased from north to south, resulting in distinct forms of *Ensatina* salamanders in southern California that differ dramatically in color and no longer interbreed.

Geographic isolation is even more obvious in other examples. The green iguana of South America is believed to be the common ancestor for both the marine iguana on the Galápagos Islands (to the west) and the rhinoceros iguana on Hispaniola, an island to the north. If so, how could it happen? Green iguanas are strong swimmers, so by chance, a few could have migrated to these islands, where they formed populations separate from each other and from the parent population back in South America. Each population continued on its own evolutionary path as new mutations, genetic drift, and different selection pressures occurred. Eventually, reproductive isolation developed, and the result was three species of iguanas that are reproductively isolated from each other.

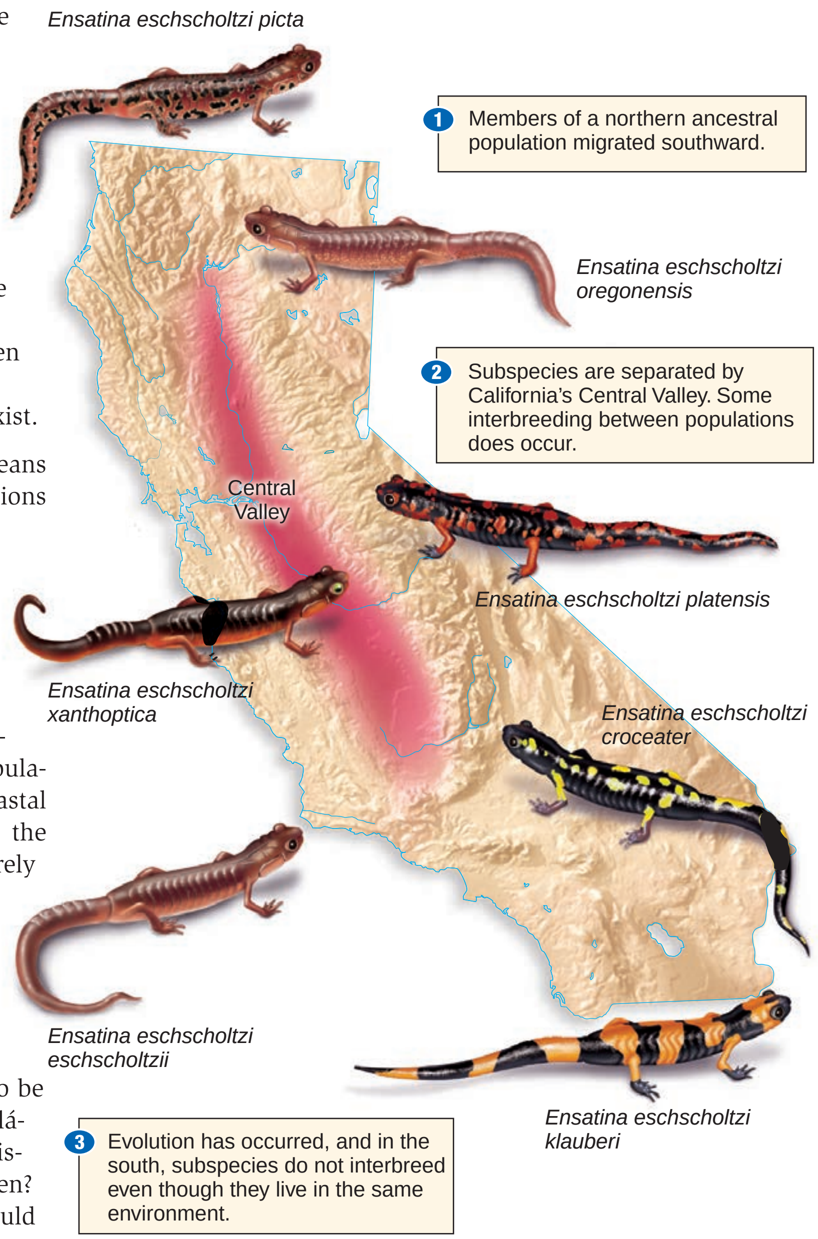

FIGURE 14.3A Allopatric speciation among *Ensatina* salamanders.

Sockeye Salmon and *Anolis* Lizards A more detailed example of allopatric speciation involves sockeye salmon in Washington state. In the 1930s and 1940s, hundreds of thousands of sockeye salmon were introduced into Lake Washington.

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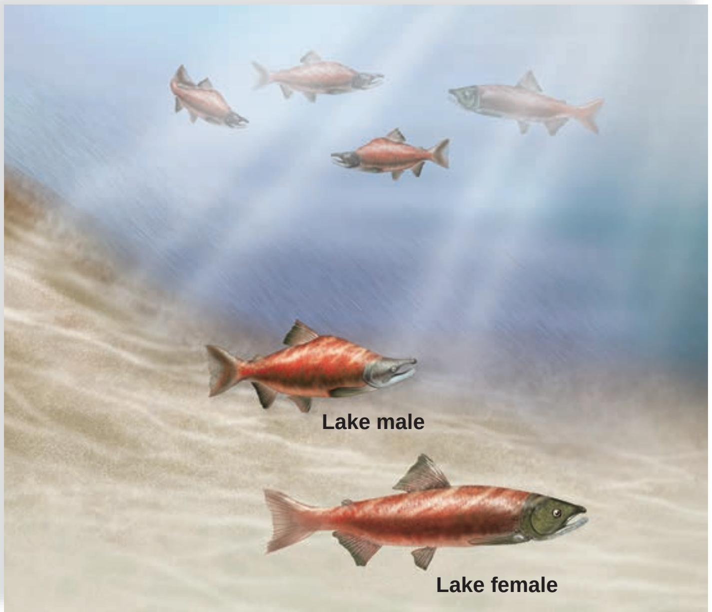


FIGURE 14.3B Sockeye salmon at Pleasure Point Beach, Lake Washington.

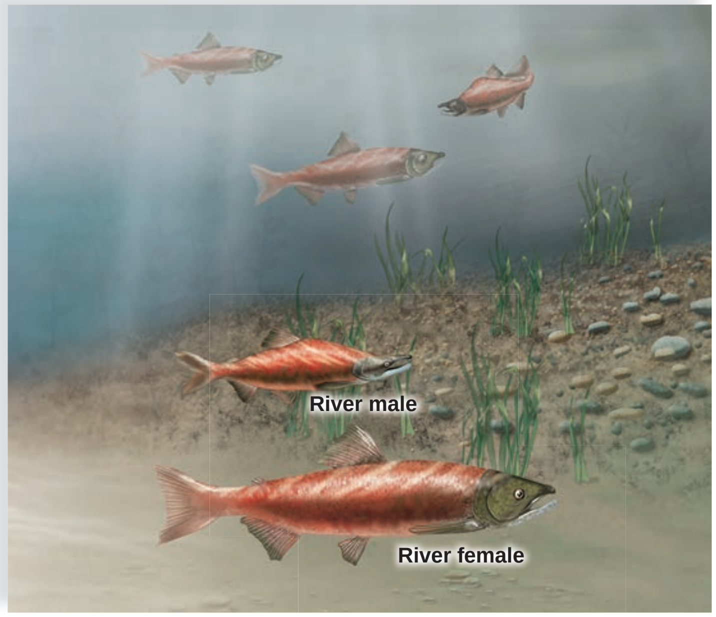
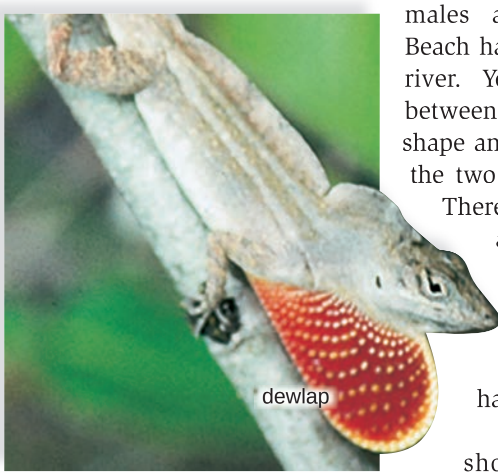


FIGURE 14.3C Sockeye salmon in Cedar River. The river connects with Lake Washington.

Some colonized an area of the lake near Pleasure Point Beach (**Fig. 14.3B**). Others migrated into the Cedar River (**Fig. 14.3C**). Andrew Hendry, a biologist at McGill University, is able to tell Pleasure Point Beach salmon from Cedar River salmon because they differ in shape and size due to the demands of reproducing in the river. In the river, males tend to be more slender than those along the beach. A slender body is better able to turn sideways in a strong current, and the courtship ritual of a sockeye salmon requires this maneuver. On the other hand, the females tend to be larger than those along the beach. This larger body helps them dig slightly deeper nests in the gravel beds on the river bottom. Their deeper nests are not disturbed by river currents and will remain warm enough for egg viability.

Hendry has another way to tell beach salmon from river salmon. Ear stones called otoliths reflect variations in water temperature while a fish embryo is developing. Water temperatures at Pleasure Point Beach are relatively constant compared to Cedar River temperatures. By checking otoliths in adults, Hendry found that a third of the sockeye males at Pleasure Point Beach had grown up in the river. Yet the distinction between male and female shape and size according to the two locations remains. Therefore, these males are not successful breeders along the beach. In other words, reproductive isolation has occurred.



This example shows that a side effect to adaptive changes can be reproductive isolation. Another example is seen among *Anolis* lizards, which court females by extending a colorful flap of skin, called a "dewlap." The dewlap must be seen in order to attract mates. Therefore, populations of *Anolis* in a dim forest tend to evolve light-colored dewlaps that reflect light, while populations in open habitats evolve dark-colored dewlaps. This change in dewlap color causes the populations to be reproductively isolated, because females distinguish males of their species by the color of the dewlap.

***Ficedula* Flycatchers** As populations become reproductively isolated, postzygotic isolating mechanisms may arise before prezygotic isolating mechanisms. Postzygotic isolating mechanisms can keep species separate but they represent a large investment of energy to no avail. For example, the production of a hybrid requires an investment of energy that does not result in the passage of genes to future generations. Therefore, natural selection would favor the evolution of prezygotic isolating mechanisms over postzygotic isolating mechanisms. The term *reinforcement* is given to the process of natural selection favoring variations that lead to prezygotic reproductive isolation. An example of reinforcement has been seen in *Ficedula* flycatchers of the Czech Republic and Slovakia. When the pied and collared flycatchers occur in close proximity, the pied flycatchers have evolved a different coat color from that of the collared flycatchers. The difference in color helps the two species recognize and mate with their own species.

Adaptation to new environments can result in multiple species from a single ancestral species, as discussed in Section 14.4.

14.3 Check Your Progress **Knowing that the coat colors of lions and tigers is adaptive to their habitats, construct a hypothetical scenario by which they evolved from an ancestral species.**

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14.4 Adaptive radiation produces many related species

Adaptive radiation occurs when a single ancestral species gives rise to a variety of species, each adapted to a specific environment. An *ecological niche* is where a species lives and how it interacts with other species. When an ancestral finch arrived on the Galápagos Islands, its descendants spread out to occupy various niches. Geographic isolation of the various finch populations caused their gene pools to become isolated. Because of natural selection, each population adapted to a particular habitat on its island. In time, the many populations became so genotypically different that now, when by chance they reside on the same island, they do not interbreed, and are therefore separate species. The finches use beak shape to recognize members of the same species during courtship. Rejection of suitors with the wrong type of beak is a behavioral type of prezygotic isolating mechanism.

Similarly, on the Hawaiian Islands, a wide variety of honeycreepers are descended from a common goldfinch-like ancestor that arrived from Asia or North America about 5 million years ago. Today, honeycreepers have a range of beak sizes and shapes for feeding on various food sources, including seeds, fruits, flowers, and insects (**Fig. 14.4**).

Adaptive radiation has occurred in both plants and animals throughout the history of life on Earth when a group of organisms exploits a new environment. For example, with the demise of the dinosaurs about 66 million years ago, mammals underwent adaptive radiation as they exploited niches previously occupied by the dinosaurs.

This completes our discussion of allopatric speciation. The next part of the chapter discusses speciation when there is no geographic barrier.

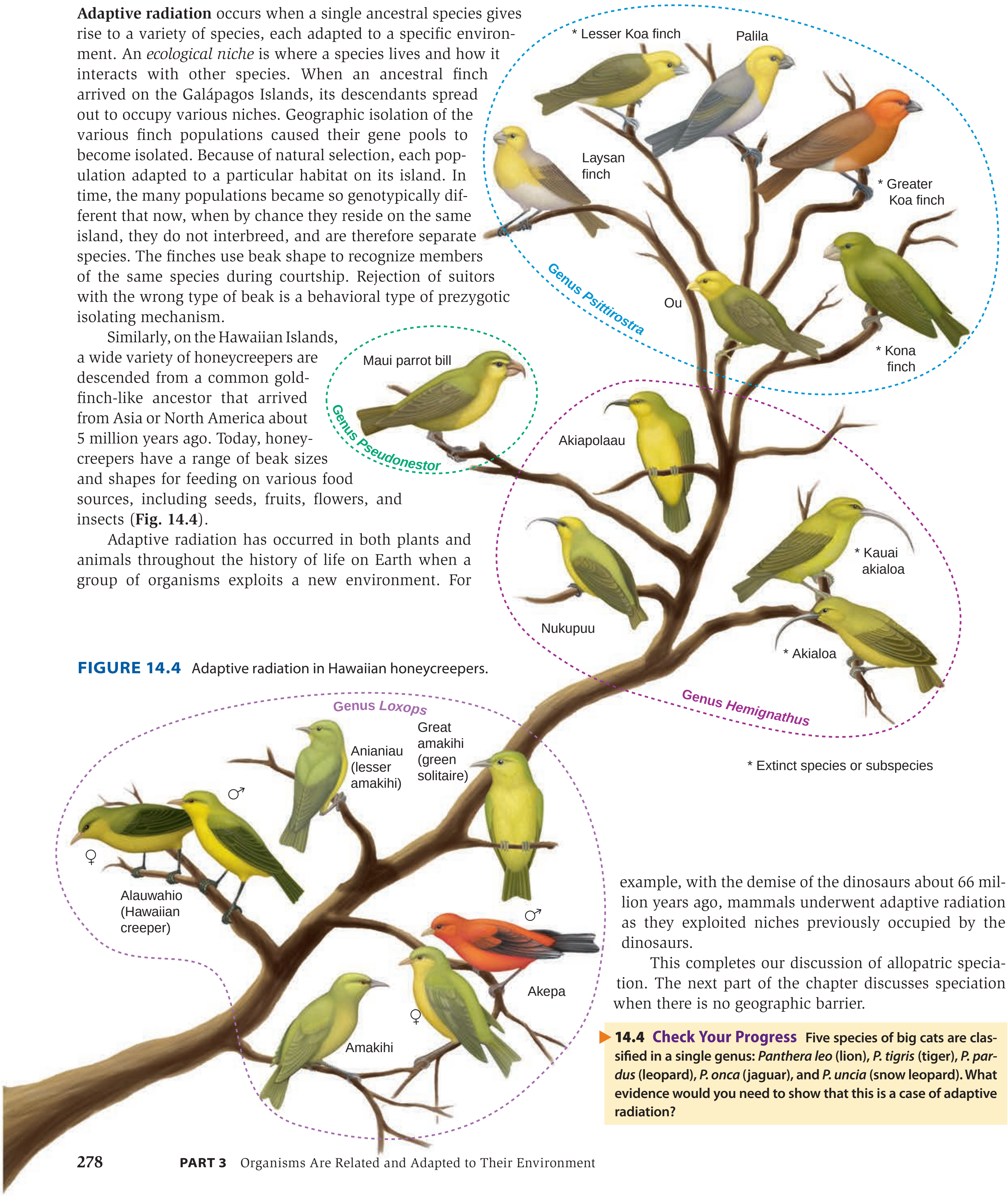

FIGURE 14.4 Adaptive radiation in Hawaiian honeycreepers.

14.4 Check Your Progress **Five species of big cats are classified in a single genus: *Panthera leo* (lion), *P. tigris* (tiger), *P. pardus* (leopard), *P. onca* (jaguar), and *P. uncia* (snow leopard). What evidence would you need to show that this is a case of adaptive radiation?**

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Origin of Species Can Occur in One Place

Learning Outcomes

- Relate sympatric speciation in plants to polyploidy. (14.5)
- Distinguish between autoploidy and alloploidy. (14.5)

Speciation without the presence of a geographic barrier does occur, and the best examples are due to chromosome number changes in plants. Hybridization, followed by doubling of the chromosome number, can occur naturally or as a result of artificial selection. Such events must have occurred during the artificial selection of corn over the years.

14.5 Speciation occasionally occurs without a geographic barrier

Speciation without the presence of a geographic barrier is termed **sympatric speciation.** Sympatric speciation has been difficult to substantiate in animals. For example, two populations of the Meadow Brown butterfly, *Maniola jurtina,* have different distributions of wing spots. The two populations are both in Cornwall, England, and they maintain the difference in wing spots, even though there is no geographic boundary between them. But, as yet, no reproductive isolating mechanism has been found. In contrast, we know of instances in plants by which a postzygotic isolating mechanism has given rise to a new species within the range and habitat of the parent species. In other words, no geographic barrier was required. All instances in plants involve **polyploidy,** additional sets of chromosomes beyond the diploid (2n) number. Sympatric speciation is more common in flowering plants than in animals due to self-pollination. A polyploid plant can reproduce only with itself, and cannot reproduce with the parent (2n) population because not all the chromosomes would be able to pair during meiosis. Two types of polyploidy are known: autoploidy and alloploidy.

Speciation through **autoploidy** is seen in diploid plants when nondisjunction occurs during meiosis and the diploid species produces diploid gametes. If this diploid gamete fuses with a haploid gamete, a triploid plant results. A triploid (3n) plant is sterile and cannot produce offspring because the chromosomes cannot pair during meiosis. Humans have found a use for sterile plants because they produce fruits without seeds. **Figure 14.5A** contrasts a diploid banana with seeds to today's polyploid banana that produces no seeds. If two of the diploid gametes fuse, the plant is a tetraploid (4n) and the plant is fertile, as long as it reproduces with another of its own kind. The fruits of polyploid plants are much larger than those of diploid plants. The huge strawberries of today are produced by octaploid (8n) plants.

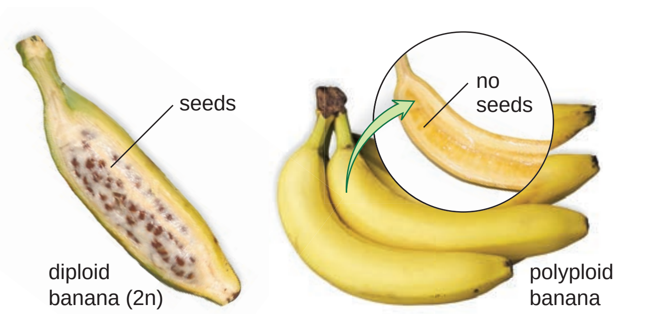

FIGURE 14.5A Autoploidy: The small, diploid-seeded banana is contrasted with the large, polyploid banana that produces no seeds.

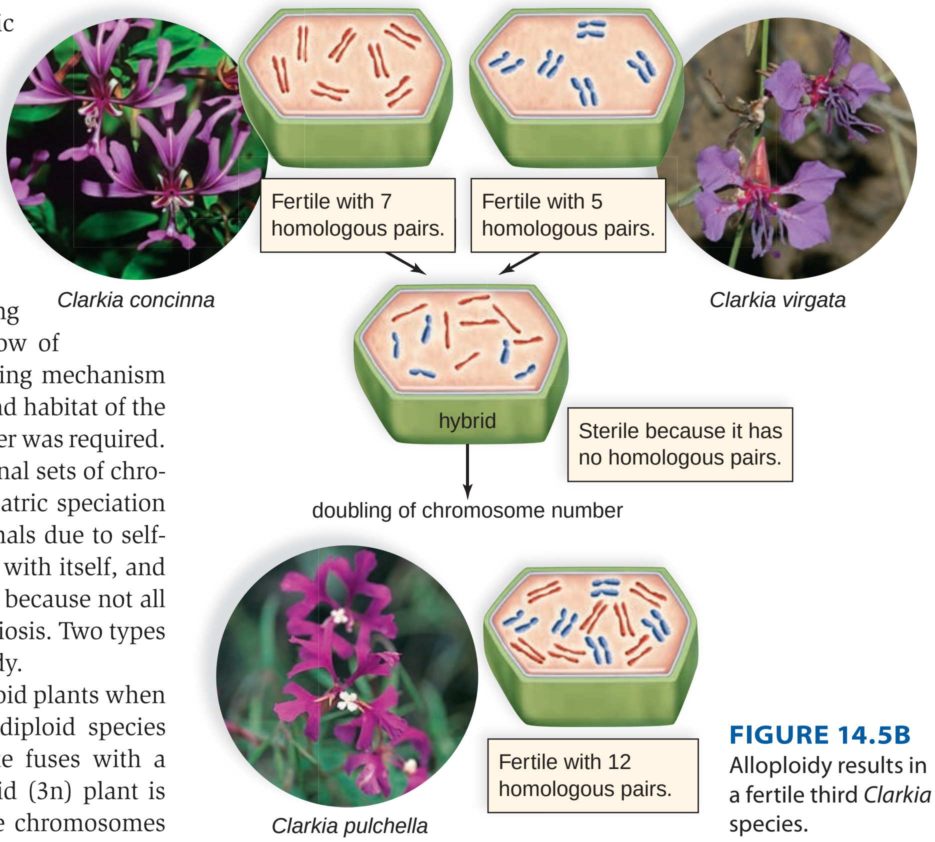

FIGURE 14.5B Alloploidy results in a fertile third *Clarkia* species.

Speciation through **alloploidy** requires two steps. The prefix *allo-,* which means "different," is appropriate because the process begins when two different but related species of plants hybridize. First, when two different but related species of plants hybridize, the hybrid is sterile because it has no homologous pairs of chromosomes. Second, if and when a doubling of the chromosome number occurs a new fertile plant results. **Figure 14.5B** gives an example of alloploidy. The Western wildflower, *Clarkia concinna,* has seven (7) pairs of homologous chromosomes; a related species, *C. virgata,* has five (5) pairs of chromosomes. The hybrid has twelve chromosomes but is sterile because it has no homologous pairs and therefore meiosis of gametogenesis cannot occur. However, researchers have located a plant now called *C. pulchella* that is fertile due to doubling of the chromosome number, which allows the twelve (12) chromosomes to pair during meiosis. Alloploidy also occurred during the evolution of the wheat plant, which is commonly used today to produce bread.

14.5 Check Your Progress **What fossil evidence might support the hypothesis that the different species of cats arose sympatrically?**

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HOW BIOLOGY IMPACTS OUR LIVES — *Application*

14A The Many Uses of Corn, an Allotetraploid

When the world record for eating corn on the cob was set at 33½ ears in 12 minutes, the last thing on anyone's mind was the evolution of corn. Corn, also known as maize (*Zea mays*), represents one of the most remarkable plant-breeding achievements in the history of agriculture. Today, modern society literally reaps the benefits of corn as a domestic product.

Modern corn bears little resemblance to its ancient ancestor, an inconspicuous wild grass called teosinte from southern Mexico. Teosinte is a drought-tolerant grass that produces reproductive spikes fairly close to the ground. Each spike is filled with two rows of small, triangular kernels (seeds) enclosed in a tough husk. Each seed is encased and protected by a hard shell. Ancient peoples discovered that teosinte was a source of food and began selecting spikes to plant near their homes, close to irrigation systems. Thus, between 4000 and 3000 B.C., the hand of artificial selection began to shape the evolution of corn.

Teosinte
(Zea mexicana)

Experimental hybridization followed, and many varieties of corn were developed. By A.D. 1070, corn had reached North America and was being grown by the Iroquois in New York. By the time Columbus visited the Americas, corn was being grown in a number of environments. Columbus even commented on the fields of corn and its great taste. We now know that corn is an allotetraploid, meaning it is 4n. Hybridization between two related species must have been followed by doubling of the chromosomes, accounting for why ears of corn are now so large (**Fig. 14A**).

Today corn is America's number-one field crop, yielding approximately 9.5 billion bushels yearly. It is an important food source for both humans and livestock. Corn is a component of over 3,000 grocery products, including cereals, corn syrup, cornstarch, ice cream, soft drinks, chips, snack foods, and even peanut butter. It is also used in making glue, shoe polish, ink, soaps, and synthetic rubber. Now, corn is also a source for the production of ethanol to fuel our vehicles. The uses of corn seem to be limited only by our imaginations (Fig. 14A).

FORM YOUR OPINION

1. Using corn to produce ethanol raises the cost of corn because it makes less available for food and feed in the United States and abroad. Should we continue to convert corn to ethanol? Why or why not?
2. Much corn is grown as feed for animals. The sewage produced by animals, can be a threat to our health and eating beef can lead to circulatory problems. Should we stop eating beef?

FIGURE 14A Among the many of its uses today, corn is a fuel source, a component of many products that absorb water, a feed for animals and a delicious food for people.

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Macroevolution Involves Changes at the Species Level and Beyond

Learning Outcomes

- Compare and contrast the gradualistic model of speciation with the punctuated equilibrium model. (14.6)
- Explain how the developmental process could have contributed to speciation and higher classification categories. (14.7)
- Use the evolution of the horse to show that evolution is not goal-oriented. (14.8)

The gradualistic model of speciation can be contrasted with the punctuated equilibrium model. The gradualistic model predicts transitional links that may fossilize while the punctuated equilibrium model predicts few, if any, transitional links in the fossil record. Studies of developmental regulatory *Hox* genes show us that developmental changes could contribute to rapid speciation. Still, any phenotypic change, even if it occurs rapidly, is subject to natural selection, and when we view, say, the evolution of the horse, we see no constant pattern toward a goal.

14.6 Speciation occurs at different tempos

Many evolutionists conclude, as Darwin did, that evolutionary changes occur gradually. Therefore, these evolutionists support a *gradualistic model,* which proposes that speciation occurs after populations become isolated, with each group continuing slowly on its own evolutionary pathway. These evolutionists often show the history of groups of organisms by drawing the type of diagram shown in **Figure 14.6A.** Note that in this diagram, an ancestral species has given rise to two separate species, represented by a slow change in plumage color. The gradualistic model suggests that it is difficult to indicate when speciation occurred because there would be so many transitional links. However, in some cases, it has been possible to trace the evolution of a group of organisms by finding transitional links.

After studying the fossil record, some paleontologists tell us that species can appear quite suddenly, and then they remain essentially unchanged phenotypically until they undergo extinction. Based on these findings, they developed a *punctuated equilibrium model* to explain the pace of evolution. This model says that periods of equilibrium (no change) are punctuated (interrupted) by speciation. **Figure 14.6B** shows this way of representing the history of evolution over time. This model suggests that transitional links are less likely to become fossils and less likely to be found. Moreover, speciation is apt to involve an isolated population at one locale, because a favorable genotype could spread more rapidly within such a population. Only when this population expands and replaces other species is it apt to show up in the fossil record.

A strong argument can be made that it is not necessary to choose between these two models of evolution and that both could very well assist us in interpreting the fossil record. In a stable environment, a species may be kept in equilibrium by stabilizing selection for a long period. If environmental change is rapid, a new species may arise suddenly before the parent species goes on to extinction. Because geologic time is measured in millions of years, the "sudden" appearance of a new species in the fossil record could actually represent many thousands of years. Using only a small rate of change (.0008/year), two investigators calculated that the brain size in the human lineage could have increased from 900 cm^3 to 1,400 cm^3 in only 135,000 years. This would be a very rapid change in the fossil record. Actually, the record indicates that brain enlargement took about 500,000 years, indicating that the real pace was slower than it might have been.

14.6 Check Your Progress **If a paleontologist were to find ligers in the fossil record, could she/he use that data to substantiate a gradualistic or a punctuated equilibrium model of evolution? Explain.**

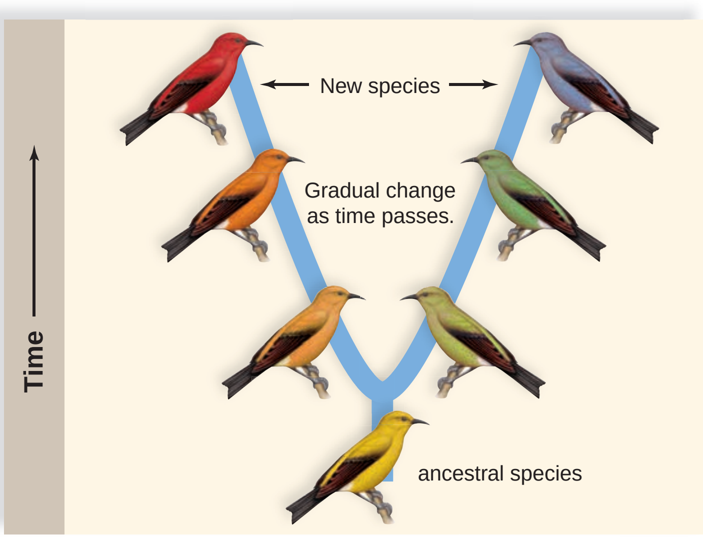

FIGURE 14.6A Gradualistic model of speciation.

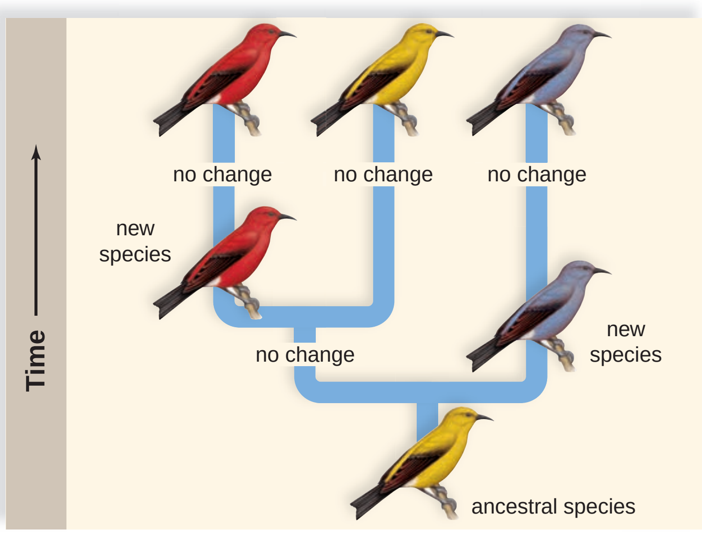

FIGURE 14.6B Punctuated equilibrium model of speciation.

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14B The Burgess Shale Hosts a Diversity of Life

Finding the Burgess Shale, a rock outcropping in Yoho National Park, British Columbia, was a chance happening. In 1909, Charles Doolittle Walcott of the Smithsonian Institute was out riding when his horse stopped in front of a rock made of shale. He cracked the rock open and saw the now-famous fossils of the animals depicted in **Figure 14B.** Walcott and his team began working the site and continued on their own for quite a few years. Around 1960, other paleontologists became interested in studying the Burgess Shale fossils.

As a result of uplifting and erosion, the intriguing fossils of the Burgess Shale are relatively common in that particular area. However, the highly delicate impressions and films found in the rocks are very difficult to remove from their matrix. Early attempts to remove the fossils involved splitting the rocks along their sedimentary plane and using rock saws. Unfortunately, these methods were literally "shots in the dark," and many valuable fossils were destroyed in the process. New methods, involving ultraviolet light to see the fossils and diluted acetic acid solutions to remove the matrix, have been more successful in freeing the fossils.

The fossils tell a remarkable story of marine life some 540 MYA (millions of years ago). In addition to fossils of organisms that had external skeletons, many of the fossils are remains of soft-bodied invertebrates; these are a great find because soft-bodied animals rarely fossilize. During this time, all organisms lived in the sea, and it is believed the barren land was subject to mudslides, which entered the ocean and buried the animals, killing them. Later, the mud turned into shale, and later still, an upheaval raised the shale. Before the shale formed, fine mud particles filled the spaces in and around the organisms so that the soft tissues were preserved and the fossils became somewhat three-dimensional.

FIGURE 14B *Above:* The Burgess Shale quarry, where many ancient fossils have been found. *Right:* An artist's depiction of the variety of fossils is accompanied by photos of the actual fossilized remains.

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The fossils tell us that the ancient seas were teeming with weird-looking, invertebrate animals. All of today's groups of animals can trace their ancestry to one of these strange-looking forms, which include sponges, arthropods, worms, and trilobites, as well as spiked creatures and oversized predators. The animals featured in Figure 14B have been assigned to these genera and because they are believed to be the type of animal mentioned:

Opabinia, a crustacean
Thaumaptilon, a sea pen
Vauxia, a sponge
Wiwaxia, a segmented worm

The vertebrates, including humans, are descended from *Pikaia,* the only one of the fossils that has a supporting rod called a notochord. (In vertebrates, the notochord is replaced by the vertebral column during development.)

Unicellular organisms have also been preserved at the Burgess Shale site. They appear to be bacteria, cyanobacteria, dinoflagellates, and other protists. Fragments of algae are preserved in thin, shiny carbon films. A technique has been perfected that allows the films to be peeled off the rocks.

Anyone can travel to Yoho National Park, look at the fossils, and get an idea of the types of animals that dominated the world's oceans for nearly 300 million years. Some of the animals had external skeletons, but many were soft-bodied. Interpretations of the fossils vary. Some authorities hypothesize that the great variety of animals in the Burgess Shale evolved within 20–50 million years, and therefore the site supports the hypothesis of punctuated equilibrium. Others believe that the animals started evolving much earlier and that we are looking at the end result of an adaptive radiation requiring many more millions of years to accomplish. Some investigators present evidence that all the animals are related to today's animals and should be classified as such. Others believe that several of them are unique creatures unrelated to the animals of today. Regardless of the controversies, the fossils tell us that speciation, diversification, and eventual extinction are part of the history of life.

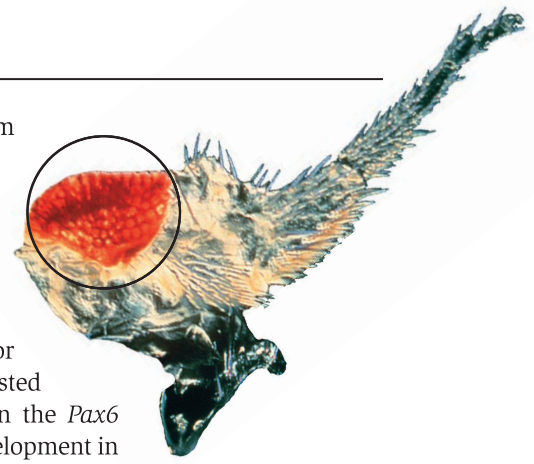
FORM YOUR OPINION

1. What should the scientific community do when confronted with a phenomenon like the Burgess Shale?
2. Should students be exposed to phenomena that cannot as yet be fully explained? Why or why not?

14.7 Development plays a role in speciation

Whether slow or fast, how could evolution have produced the myriad of animals in the Burgess Shale and, indeed, in the history of life? Or, to ask the question in a genetic context, how can genetic changes bring about such major differences in form? It has been suggested since the time of Darwin that the answer must involve developmental processes. In 1917, D'Arcy Thompson asked us to imagine an ancestor in which all parts are developing at a particular rate. A change in regulatory gene expression could stop a developmental process or continue it beyond its normal time. For instance, if the growth of limb bones were stopped early, the result would be shorter limbs, and if it were extended, the result would be longer limbs compared to those of an ancestor. Or, if the whole period of growth were extended, a larger animal would result, accounting for why some species of horses are so large today.

Using new kinds of microscopes and the modern techniques of cloning and manipulating genes, investigators have indeed discovered genes whose *differential expression* can bring about changes in body shapes (**Fig. 14.7A**). More surprisingly, these same regulatory genes occur in all organisms. This finding suggests that these genes must date back to a common ancestor that lived more than 600 MYA (before the Burgess Shale animals), and that despite millions of years of divergent evolution, all animals share the same regulatory switches for development. Previously in Section 11.4, p. 216, we pointed out how the same regulatory gene, *Pax6,* turns on eye development even though the animal kingdom contains many different types of eyes, and it was long thought that each type would require its own set of genes. Flies, crabs, and other arthropods have compound eyes composed of hundreds of individual visual units. Humans and all other vertebrates have a camera-type eye with a single lens. So do squids and octopuses. Humans are not closely related to either flies or squids, so wouldn't it seem likely that all three types of animals evolved "eye" genes separately? Not so. In 1994, Walter Gehring and his colleagues at the University of Basel, Switzerland, discovered that *Pax6* is required for eye formation in all animals tested (see Fig. 11.4B). Mutations in the *Pax6* gene lead to failure of eye development in both people and mice, and remarkably, the mouse *Pax6* gene can cause an eye to develop on the leg of a fruit fly.



Eye on fruit fly leg.

Despite millions of years of divergent evolution, all animals share the same regulatory genes for development.

Increase in Complexity The developmental regulatory genes called *Hox* genes have been much studied, and investigators tell us that the number of these genes increased twice during the evolution of animals. Both expansions are associated with an increase in complexity, defined by the appearance of different cell types. One expansion occurred during the evolution of vertebrates. Invertebrates have 13 *Hox* genes, while vertebrates, including humans, have four copies of the 13 *Hox* gene set. It appears that the set underwent a series of duplications, and some of the duplicate genes may have taken on new functions, a process mentioned in How Life Changes, p. 262. Similarly, some other sets of regulatory genes that operate in development were duplicated when vertebrates evolved. This increase in the number of regulatory gene numbers may have contributed to the evolution of vertebrates and to their complexity.

The limbs of these terrestrial mammals are shaped for running (or walking).

The limbs of birds are shaped for flight.

FIGURE 14.7A Differential expression of the same regulatory genes during development can account for differences in vertebrate limbs.

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Development of Limbs Wings and arms are very different, but both humans and birds express the *Tbx5* regulatory gene in developing limb buds. *Tbx5* codes for a transcription factor that turns on the genes needed to make a limb. What seems to have changed as birds and mammals evolved are the genes that *Tbx5* turns on. Perhaps in an ancestral tetrapod, the Tbx5 protein triggered the transcription of only one gene. In mammals and birds, a few genes are expressed in response to Tbx5 protein, but the particular genes are different.

Hindlimb reduction has occurred during the evolution of other mammals. For example, as whales and manatees evolved from land-dwelling ancestors into fully aquatic forms, the hindlimbs became greatly reduced in size. Similarly, legless lizards have evolved many times. A stickleback study has shown how natural selection can lead to major skeletal changes in a relatively short time. The three-spined stickleback fish occurs in two forms in North American lakes. In the open waters of a lake, long pelvic spines help protect the stickleback from being eaten by large predators. But on the lake bottom, long pelvic spines are a disadvantage because dragonfly larvae seize and feed on young sticklebacks by grabbing them by their spines. The presence of short spines in bottom-dwelling stickleback fish can be traced to a reduction in the development of the pelvic-fin bud in the embryo, and this reduction is due to the altered expression of a regulatory gene.

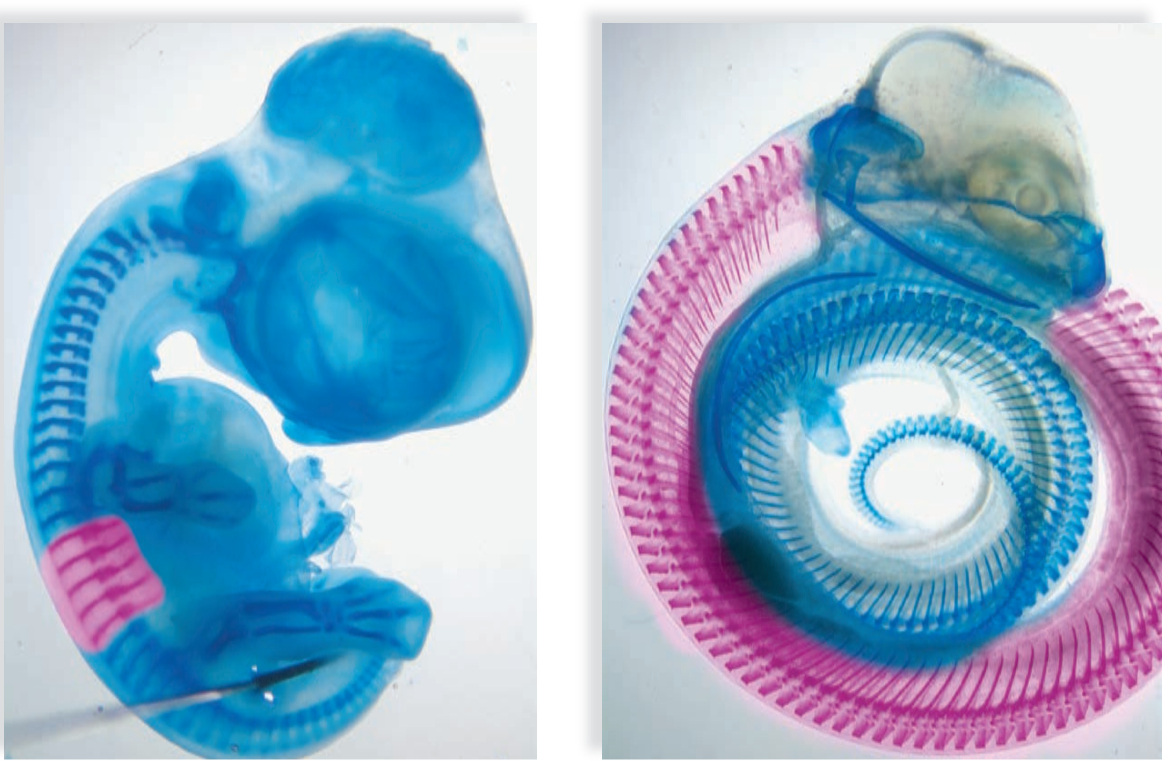
Animal diversity is due in large part to variations in the expression of ancient regulatory genes during development.

Development of Overall Shape Vertebrates have repeating segments, as exemplified by the vertebral column. In general, *Hox* genes control the development of repeated structures along the main body axes of vertebrates. Shifts in how long *Hox* genes are expressed per segment in embryos are responsible for why the snake has hundreds of rib-bearing vertebrae and essentially no neck in contrast to other vertebrates, such as a chick (**Fig. 14.7B**). Changes in the timing of *Hox* gene expression can also account for the evolution of four legs rather than a fin. In vertebrates with legs, the *Hox* genes are turned on again in a later phase of development. This phase is associated with the further growth outwards of the limb bones to form the limb and digits where a fin formerly existed. On the other hand, the inability of a *Hox* gene to turn on other regulatory genes in certain segments can explain why insects have just six legs, and other arthropods, such as crayfish, have ten legs. In general, the study of *Hox* genes has shown how animal diversity is due to variations in the expression of ancient genes rather than to wholly new and different genes.

Human Evolution The sequencing of genomes has shown us that our DNA base sequence is very similar to that of chimpanzees, mice, and, indeed, all vertebrates. Based on this knowledge and the work just described, investigators no longer expect to find new genes to account for the evolution of humans. Instead, they predict that differential gene expression and/or new functions for "old" genes will explain how humans evolved.

We have to keep in mind that developmental changes result in a phenotype that is subject to natural selection. We would expect that during the history of life many changes in phenotype were not advantageous and therefore did not become prevalent in future generations.

14.7 Check Your Progress **a. Why does it seem that differential regulatory gene expression must occur during the development of ligers? Why might their numbers increase? b. Assume ligers live in the wild and they can reproduce. Create a scenario by which their numbers increase while those of lions and tigers decrease.**



a. b.

FIGURE 14.7B
Differential expression of a *Hox* gene causes **(a)** a chick to have fewer vertebrae than **(b)** a snake in a particular region (colored pink) of the spine.

Burke, A. C. 2000. *Hox* genes and the global patterning of the somitic mesoderm. In Somitogenesis. C. Ordahl (ed.) *Current Topics in Developmental Biology,* Vol. 47. Academic Press.

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14.8 Speciation is not goal-oriented

The evolution of the horse, *Equus,* has been studied since the 1870s, and at first the ancestry of this genus seemed to represent a model for gradual, straight-line evolution until its goal, the modern horse, had been achieved. Three trends were particularly evident during the evolution of the horse: increase in overall size, toe reduction, and change in tooth size and shape.

By now, however, many more fossils have been found, making it easier to tell that the lineage of a horse is complicated by the presence of many ancestors with varied traits. The family tree in **Figure 14.8** is an oversimplification because each of the names is a genus that contains several species, and not all past genera in the horse family are included. It is apparent, then, that the ancestors of *Equus* form a thick bush of many equine species and that straight-line evolution did not occur. Because *Equus* alone remains and the other genera have died out, it might seem as if evolution was directed toward producing *Equus,* but this is not the case. Instead, each of these ancestral species was adapted to its environment. Adaptation occurs only because the members of a population with an advantage are able to have more offspring than other members. Natural selection is opportunistic, not goal-oriented.

Fossils named *Hyracotherium* have been designated as the first probable members of the horse family, living about 57 MYA. These animals had a wooded habitat, ate leaves and fruit, and were about the size of a dog. Their short legs and broad feet with several toes would have allowed them to scamper from thicket to thicket to avoid predators. *Hyracotherium* was obviously well adapted to its environment because this genus survived for 20 million years.

The family tree of *Equus* tells us once more that speciation, diversification, and extinction are common occurrences in the fossil record. The first adaptive radiation of horses occurred about 35 MYA. The weather was becoming drier, and grasses were evolving. Eating grass requires tougher teeth, and an increase in size and longer legs would have permitted greater speed to escape enemies. The second adaptive radiation of horses occurred about 15 MYA and included *Merychippus* as a representative of these groups of speedy grazers that lived on the open plain. By 10 MYA, the horse family had become quite diversified. Some species were large forest browsers, some were small forest browsers, and others were large plains grazers. Many species had three toes, but some had one strong toe. (The hoof of the modern horse includes only one toe.)

Modern horses evolved about 4 MYA from ancestors who had features adaptive for living on an open plain, such as large size, long legs, hoofed feet, and strong teeth. The other groups of horses prevalent at the time became extinct, no doubt for complex reasons.

▶ **14.8 Check Your Progress** **There are only five species of cats in the genus *Panthera.* Does this represent a goal of evolution?**

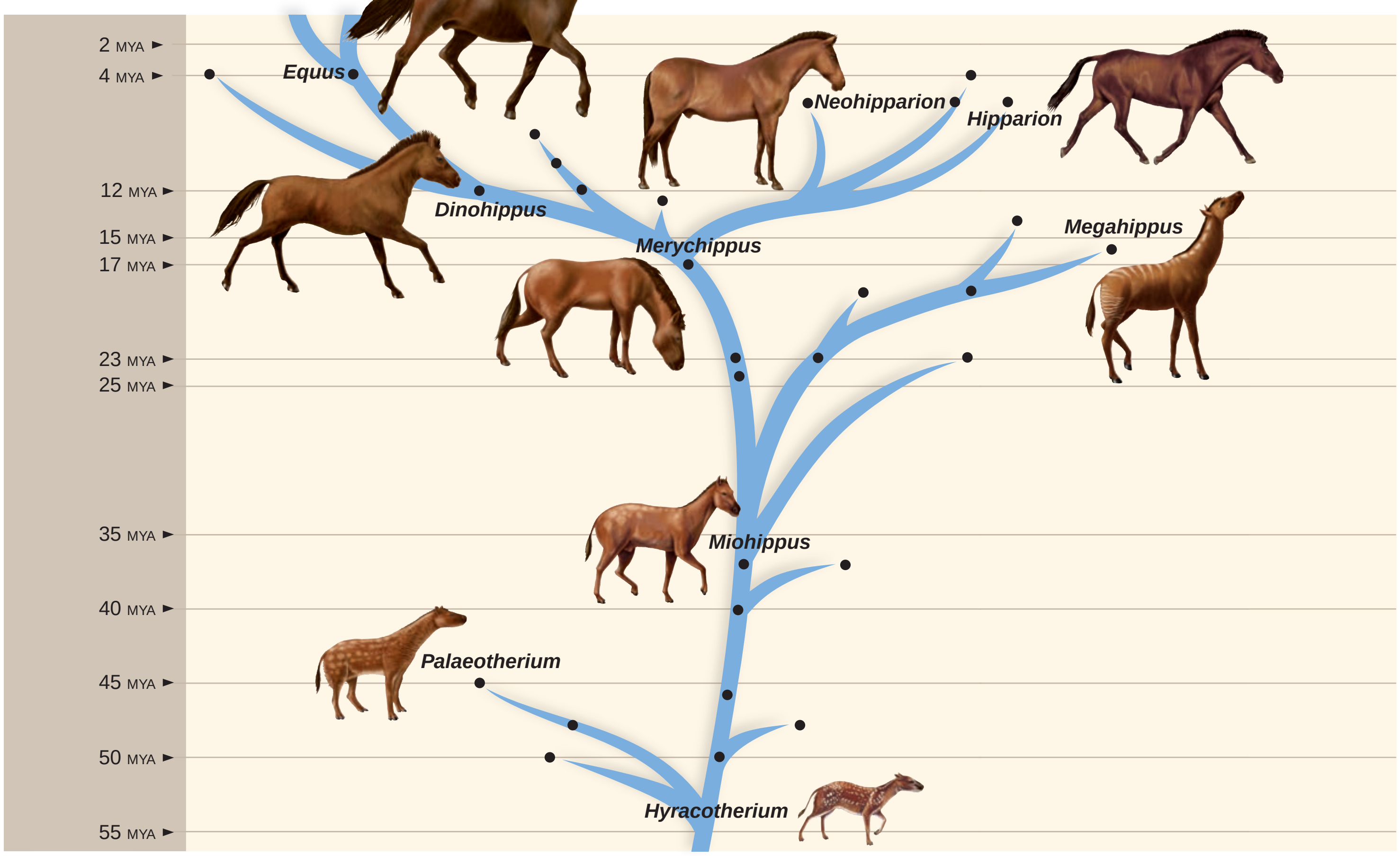

FIGURE 14.8 Simplified family tree of *Equus.* Every dot represents a genus.

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THE CHAPTER IN REVIEW

SUMMARY

Evolution of Diversity Requires Speciation

14.1 Species have been defined in more than one way

- **Macroevolution** depends on speciation.
- **Speciation** occurs when one species splits into two or more species or when one species becomes a new species over time.
- According to the **evolutionary species concept,** every species has its own evolutionary history, and a species can be recognized by diagnostic traits.
- According to the **biological species concept,** members of a species are reproductively isolated from members of other species. They can only reproduce with members of their own species.

14.2 Reproductive barriers maintain genetic differences between species

- **Prezygotic isolating mechanisms** prevent reproductive attempts.
- **Postzygotic isolating mechanisms** prevent zygote development or F_1 and F_2 hybrid offspring from breeding.

Prezygotic Isolating Mechanisms		Postzygotic Isolating Mechanisms
Premating →	Mating →	Fertilization
Habitat isolation	Mechanical isolation	Zygote mortality
Temporal isolation	Gamete isolation	Hybrid sterility
Behavioral isolation		F_2 fitness

Origin of Species Usually Requires Geographic Separation

14.3 Allopatric speciation utilizes a geographic barrier

- **Allopatric speciation** begins when populations derived from a larger one are separated by a barrier and they start to differ genetically and phenotypically.
- Following separation, postzygotic mechanisms followed by prezygotic mechanisms can develop over time.

14.4 Adaptive radiation produces many related species

- When **adaptative radiation** occurs, several new species evolve from an ancestral species, and they adapt to fill different niches separated by geographic barriers.
- The many types of Hawaiian honeycreepers are a result of adaptive radiation.

Origin of Species Can Occur in One Place

14.5 Speciation occasionally occurs without a geographic barrier

- **Sympatric speciation** occurs without a geographic barrier.
- **Polyploidy** is present when plants have additional sets of chromosomes beyond the diploid (2n) number. The sudden occurrence of polyploidy is speciation because a polyploid cannot reproduce with parental 2n plants.
- Speciation through **autoploidy** occurs when a diploid gamete fuses with a haploid gamete, resulting in a triploid plant, which is sterile.
- Speciation through **alloploidy** occurs when two different but related species of plants hybridize, and then the chromosome number doubles making the hybrid fertile.

Macroevolution Involves Changes at the Species Level and Beyond

14.6 Speciation occurs at different tempos

- According to the gradualistic model, speciation occurs gradually, perhaps due to a gradually changing environment.
- According to the punctuated equilibrium model, periods of equilibrium are interrupted by rapid speciation. Perhaps, if the environment changes rapidly, new species may suddenly arise.
- On occasion, fossil record data may fit one model of speciation, and on another occasion, it may fit the other model.
- Speciation, diversification, and eventual extinction are part of the history of life.

14.7 Development plays a role in speciation

- Despite millions of years of divergent evolution, all animals share the same regulatory genes for development.
- *Hox* gene duplications could have brought about increased complexity in animals.
- Eye development, limb development, and shape determination are controlled by the same regulatory genes in different animals. But differential expression can account for differences in outcome.
- Investigators hypothesize that differential gene expression during development coupled with natural selection can account for the process of evolution, including human evolution.

14.8 Speciation is not goal-oriented

- In horses, each ancestral species adapted to its environment, but due to a changing environment, only *Equus* survived.
- The family record of *Equus* shows speciation, diversification, and extinction. At least two major adaptive radiations occurred in the past.
- Natural selection is opportunistic, not goal-oriented; adaptation occurs because members with an advantage can have more offspring.

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TESTING YOURSELF

Evolution of Diversity Requires Speciation

1. A biological species
   a. always looks different from other species.
   b. always has a different chromosome number from that of other species.
   c. is reproductively isolated from other species.
   d. never occupies the same niche in different environments.

For questions 2–7, indicate the type of isolating mechanism described in each scenario.

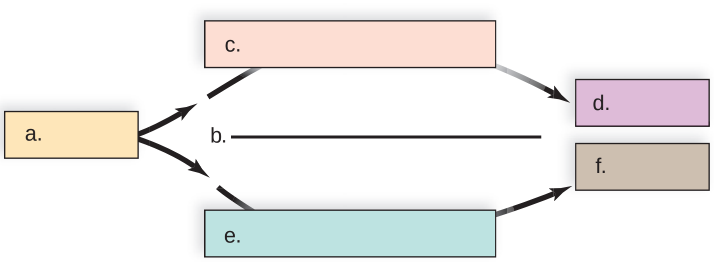
KEY:

a. habitat isolation	e. gamete isolation
b. temporal isolation	f. zygote mortality
c. behavioral isolation	g. hybrid sterility
d. mechanical isolation	h. low F_2 fitness

2. Males of one species do not recognize the courtship behaviors of females of another species.
3. One species reproduces at a different time than another species.
4. A cross between two species produces a zygote that always dies.
5. Two species do not interbreed because they occupy different areas.
6. The sperm of one species cannot survive in the reproductive tract of another species.
7. The offspring of two hybrid individuals exhibit poor vigor.
8. Which of these is a prezygotic isolating mechanism?
   a. habitat isolation
   b. temporal isolation
   c. hybrid sterility
   d. zygote mortality
   e. Both a and b are correct.
9. Male moths recognize females of their species by sensing chemical signals called pheromones. This is an example of
   a. gamete isolation.
   b. habitat isolation.
   c. behavioral isolation.
   d. mechanical isolation.
   e. temporal isolation.
10. Which of these is mechanical isolation?
    a. Sperm cannot reach or fertilize an egg.
    b. Courtship patterns differ.
    c. The organisms live in different locales.
    d. The organisms reproduce at different times of the year.
    e. Genitalia are unsuited to each other.
11. **THINKING CONCEPTUALLY** Regardless of how speciation occurs or how species are defined, what is required for separate species to be present?

Origin of Species Usually Requires Geographic Separation

12. Complete the following diagram illustrating allopatric speciation by using these phrases: genetic changes (used twice), geographic barrier, species 1, species 2, species 3.



13. The creation of new species without the need of a geographic barrier is called
    a. isolation speciation.
    b. allopatric speciation.
    c. allelomorphic speciation.
    d. sympatric speciation.
    e. symbiotic speciation.
14. The many species of Galápagos finches are each adapted to eating different foods. This is the result of
    a. gene flow.
    b. adaptive radiation.
    c. sympatric speciation.
    d. genetic drift.
    e. All of these are correct.
15. **THINKING CONCEPTUALLY** The Hawaiian Islands are some distance from any mainland, and the plants and animals on each island are unique. Only short distances separate the Florida Keys from each other and the mainland. The mainland and the Keys all contain the same species. Explain.

Origin of Species Can Occur in One Place

16. Allopatric, but not sympatric, speciation requires
    a. reproductive isolation.
    b. geographic isolation.
    c. spontaneous differences in males and females.
    d. prior hybridization.
    e. rapid rate of mutation.
17. Which of the following is not a characteristic of plant alloploidy?
    a. hybridization
    b. chromosome doubling
    c. self-fertilization
    d. All of these are characteristics of plant alloploidy.
18. Corn is an allotetraploid, which means that its
    a. chromosome number is 4n.
    b. development resulted from hybridization.
    c. development required a geographic barrier.
    d. Both a and b are correct.

Macroevolution Involves Changes at the Species Level and Beyond

19. Transitional links are least likely to be found if evolution proceeds according to the
    a. gradualistic model.
    b. punctuated equilibrium model.
    c. Both a and b are correct.
    d. None of these are correct.
20. Adaptive radiation is only possible if evolution is punctuated.
    a. true
    b. false
21. Why are there no fish fossils in the Burgess Shale?
    a. The habitat was not aquatic.
    b. Fish do not fossilize easily because they do not have shells.
    c. The fossils of the Burgess Shale predate vertebrate animals.
    d. There are fish fossils in the Burgess Shale.
22. Which of the following can influence the rapid development of new species of animals?
    a. the influence of molecular clocks
    b. a change in the expression of regulating genes
    c. the sequential expression of genes
    d. All of these are correct.
23. Which of the following does not seem to influence speciation?
    a. the evolution of different types of *Hox* genes

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b. the evolution of new types of genes that control development
c. Only the environment and not genes influence speciation.
d. Both a and b are correct.

24. Which gene is incorrectly matched to its function?
a. *Hox*—body shape
b. *Pax6*—body segmentation
c. *Tbx5*—limb development
d. All of these choices are correctly matched.

25. **THINKING CONCEPTUALLY** Explain the statement that "*Hox* genes are ancient genes."

26. In the evolution of the modern horse, which was the goal of the evolutionary process?
a. large size
b. single toe
c. Both a and b are correct.
d. Neither a nor b is correct.

27. Which of the following does not pertain to *Hyracotherium,* an ancestral horse genus?
a. small size
b. single toe
c. wooded habitat
d. All of these are characteristics of *Hyracotherium*.

THINKING SCIENTIFICALLY

1. You want to decide what definition of a species to use in your study. What are the advantages and disadvantages of the evolutionary and biological species concepts?
2. You decide to create a hybrid by crossing two species of plants. If the hybrid is a fertile plant that produces normal-sized fruit, what conclusion is possible?

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CONNECTING THE CONCEPTS

Macroevolution, the study of the origin and history of the species on Earth, is the subject of this chapter and the next. The biological species concept states that the members of a species have an isolated gene pool and can only reproduce with one another.

The origin of species is called speciation. Speciation usually occurs after two populations derived from a larger one are separated geographically. If the members of a salamander population are suddenly divided by a barrier, each new population becomes adapted to its particular environment over time. Eventually, the two populations may become so genetically different that even if members of each population come into contact, they will not be able to produce fertile offspring. Because gene flow between the two populations is no longer possible, the salamanders are considered separate species. Aided by geographic separation, multiple species can repeatedly arise from an ancestral species, as when a common ancestor from the mainland led to many species of Hawaiian honeycreepers, each adapted to its own particular environment.

Does speciation occur gradually, as Darwin supposed, or rapidly (in geologic time), as described by the punctuated equilibrium model? The fossils of the Burgess Shale support the punctuated equilibrium model. How can genetic changes bring about such major changes in form, whether fast or slow? Investigators have now discovered ancient regulatory genes (e.g., *Hox* genes), whose differential expression can bring about changes in body shapes and organs.

Evolution is not directed toward any particular end, and the traits of the species alive today arose through common descent with adaptations to a local environment. The subject of Chapter 15 is the evolutionary history and classification of living organisms today.

PUT THE PIECES TOGETHER

1. Scientists make observations and then formulate testable hypotheses to explain the observations. What testable hypotheses have biologists made about speciation? (*Hint:* How might species arise? What might cause them to arise?)
2. Paleontologists suggested the punctuated equilibrium model. What data did they use?
3. Is the study of evolution a scientific endeavor? Explain your reasoning.

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Appendix | Answer Key

CHAPTER 1

Check Your Progress

1.1 Observation data; observing that a worker ant produces eggs. **1.2** Test group: colonies exposed to the parasite; control group: colonies not exposed to the parasite. **1.3** a. Levels of organization from cells to organism illustrate order; (b) unicellular organisms divide, multicellular ones produce sperm and egg (c) metabolizes nutrients. **1.4** When organisms reproduce they pass on a copy of their genes. **1.5** Only by responding to stimuli can organisms remain homeostatic. **1.6** Natural ecosystems absorb pollutants. **1.7** The first suggests that humans are apes; the second means that apes and humans are on their own evolutionary pathway. **1.8** a. Domain Eukarya and kingdom Animals b. Fossil and molecular data **1.9** Better adapted members have the opportunity through natural selection to reproduce more, and in that way a species becomes adapted to its environment. **1.10** The hawk has levels of organization; catches food for herself and offspring; remains homeostatic because she can respond to stimuli, lives in a semidesert ecosystem; and is adapted to flying.

Form Your Opinion

Page 6: 1. No answer: The United States should not continue to export its current farming technology. Exporting technology that is known to be detrimental to ground water and top soil will eventually reduce agricultural yields, resulting in a food shortage. The United States would be better served to encourage sustainable farming practices like crop rotation to foster long-term success in agriculture. Yes answer: The United States should continue to export farming technology to other countries in order to support the global food market. As solutions to the long-term problems of these technologies arise, the U.S. should make these available to other countries as well. 2. Circumstances such as labor costs, profits, and marketing challenges might discourage a farmer from growing organically. These obstacles might be overcome through government subsidies for sustainable farming practices, sharing best practices through networking with successful organic farmers, and a world-wide movement towards eating primarily locally grown and seasonal produce.
Page 17: 1. Practical problems in agriculture, medicine, and conservation can be solved with a knowledge of evolution. Because we know that natural selection drives the evolution of pesticide resistant insects, changes to farming practices and pesticide use are possible. In medicine, awareness of the evolution of antibiotic resistant bacteria allows patients and doctors alike to make changes to the way antibiotics are prescribed and used. In conservation efforts, knowledge of evolution can be used to make informed decisions regarding endangered species; directed evolution can also be used to select for organisms to clean up the environment. 2. By naturally allowing for the growth of nonresistant insect populations, farmers can reduce the influence of pesticide resistant insects on their fields and farming practices. 3. The salmon must be successfully raised in an environment that mimics nature as closely as possible, with exposure to pressures such as normal predation and pathogens, for example, if they are to succeed in the wild. For instance, if the salmon have no exposure to pathogens that they might encounter in the wild, these salmon are at high risk of infection upon introduction without the benefit of building immune defenses from previous exposure.

Testing Yourself

1. a; 2. d; 3. c; 4. Scientific theories arise due to innumerable observations and experimentation. 5.b; 6. c; 7. b; 8. c; 9. c; 10. d; 11. Each type organism has its own sequence of bases in its genes. 12. e; 13. b; 14. d; 15. a; 16. d; 17. d; 18. A college campus has a location, as does an ecosystem. The populations of students, faculty, and administrators communicate with each other and the physical environment (the buildings). 19. c; 20. e; 21. d; 22. d; 23. c; 24. a; 25. c; 26. c; 27. Evolution is related to all the other theories; for example, all organisms are cellular because their common ancestor was cellular. 28. e; 29. f; 30. c; 31. g

Thinking Scientifically

1. a. Bacteria don't die in sunlight when dye is present. b. Dye is protective against UV radiation. c. Experiment consists of exposing control and test groups to UV light. d. Hypothesis is not supported. 2. Plant the same species of tomato plants in three large plots. All plots receive the same treatment, except plot 1, your control, receives no fertilizer; plot 2 receives the name brand fertilizer in the same quantity as plot 3 which receives the generic brand. Measure the tomatoes from each plot and calculate the average size to determine which plot results in the largest tomatoes.

Put the Pieces Together

Page 21: 1. One example, that shows the relationship between two theories, is the link between ecosystems and evolution. Different species of organisms are the result of evolution over time from a common ancestor. The evolution of new species creates new populations that interact to form communities, which in turn interact to form ecosystems. Ecosystems also evolve over time as new species evolve and change the populations and communities within the ecosystem. 2. The evolution of antibiotic resistant bacteria results from natural selection. Mutations in bacterial DNA created resistant individuals. These bacteria survive to reproduce in the presence of antibiotics, whereas non-resistant individuals die off. This process creates a population of antibiotic resistant bacteria.

CHAPTER 2

Check Your Progress

2.1 Carbon, nitrogen, phosphorus, sulfur. **2.2** See Figure 2.3B, page 29, in text. **2.3** a. One. Hydrogen has one shell, which is complete with two electrons; b. Two. Oxygen has two shells with six valence electrons in the outer shell. Therefore, oxygen requires two more electrons for a completed outer shell. **2.4** H^+, OH^-. **2.5** a. See Figure 2.6, page 32, in text; b. This is the formula that gives each atom a completed outer shell. **2.6** One end of the molecule is negative and the other end is positive because oxygen attacts electron more than hydrogen does. **2.7** Yes, because electropositive hydrogens are attracted to either electronegative oxygen or nitrogen. **2.8** Hydrogen bonding causes water molecules to stick together and to other polar molecules. **2.9** The air loses heat as it causes water in the pad to evaporate. **2.10** Polarity makes the emulsifiers hydrophilic. **2.11** The blocks of ice trap heat inside and prevent it from escaping to the environment. **2.12** a. H^+; b. OH^-. **2.13** a. Acidic; b. More H^+. **2.14** a. Down; b. Carbonic acid froms and releases H; therefore the pH decreases.

Form Your Opinion

Page 28: 1. Though controversy will undoubtedly arise over moral, monetary and other issues, science must be free to ask and answer questions about the world in which we live. However, scientists should conduct research with minimal risks to their own safety and that of others. As technology advances, the restrictions placed upon research should be reevaluated to ensure their relevance. With careful and balanced monitoring, scientific endeavors should be supported and encouraged. 2. Safety should be paramount in experimentation. The best way to proceed is to aware of advisements regarding safety and to learn from experience about how to modify procedures to make them safe. 3. Yes answer: Depending on the benefits that an experiment might have, I would consider being a guinea pig. However, research using people should be entirely voluntary and provide an explanation of the potential risks. I would be particularly willing to be an experimental subject in the field of medical research, especially if the results of experimentation had the potential to prove widely useful. No answer: I would not be willing to serve as a guinea pig in experiments that may prove harmful to me. Because of known risks, and the fact that the risks associated with experimentation on humans and animals cannot always be predicted, I would be unwilling to subject myself to the potentially hazardous side effects of being a human subject in experiments.
Page 38: 1. The changes in lakes due to acid rain kill fish and other wildlife and sometimes eliminate it altogether. Trees suffer as a result of acid rain's effects, becoming diseased or dying. If this continues, not only will the atmosphere's oxygen be affected, but the lumber industry will suffer. The food supply is at risk if plants as well as fish are negatively affected by acid rain. 2. Human beings must take some responsibility for what they do to the planet and make attempts to control their negative impact. Driving less could help to preserve lakes and the wildlife in them, forests, buildings made of limestone and marble, and

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the respiratory health of humans. Because of these factors, I would certainly be willing to drive less to help prevent acid rain. 3. Despite other stresses, environmental degradation should concern people at all times. If we do not preserve our planet and its ecosystems, our current way of life will become unsustainable and economic development will cease.

Testing Yourself

1. c; 2. b; 3. e; 4. d; 5. a; 6. c; 7. c; 8. d; 9. a; 10. c; 11. b; 12. a; 13. b; 14. d; 15. d; 16. Nitrogen needs three more electrons in the outer shell to be stable and each hydrogen shares one electron. 17. Gaining six electrons by sharing is not as likely as losing two electrons to become an ion. 18. a; 19. b; 20. c; 21. e; 22. Blood is transported in a tube (blood vessel) and water fills a tube due to its cohesive and adhesive properties. 23. a; 24. a; 25. a; 26. b; 27. c; 28. A bicarbonate buffer combines immediately with H^+ or OH^-, normalizing the blood pH. Respiration, by removing carbon dioxide from the blood, provides a slower response that decreases H_2CO_3 concentration. The kidneys excrete H^+ and provide the slowest of the three responses, but the kidenys also have the ability to cause the greatest overall change in the pH level.

Thinking Scientifically

1. Na^+Cl^- interrupts hydrogen bonding enough to prevent the formation of the ice lattice that forms during freezing. 2. Chemical behavior is dependent on the number of electrons in the outer shell, not the number of neutrons in the nucleus.

Put the Pieces Together

Page 41: 1. Methane gas is formed when a carbon atom binds four hydrogen atoms. The bonds of methane are nonpolar covalent bonds in which electrons are shared equally between the atoms. Each bond in methane points to a corner of a tetrahedron. Water is formed when two hydrogen atoms bind one oxygen atom. The sharing of electrons is not entirely equal in this bent molecule. Oxygen, being more electronegative attracts the electrons more than hydrogen does and the result is a polar molecule. 2. The properties of water which result from its structure are critical to life. Cohesion, adhesion, high surface tension, high heat capacity and high heat of vaporization all result from hydrogen bonding. These properties of water allow it to be a transport medium that also maintains the internal temperature of organisms. The difference in the density of frozen water compared to liquid water means that life is preserved under a layer of ice. Water being a polar molecule acts as a universal solvent that allows metabolism to occur.

CHAPTER 3

Check Your Progress

3.1 All living things contain biomolecules **3.2** Hydrophilic functional groups, which would make them water soluble. **3.3** It uses the water for hydrolysis reactions. **3.4** Fructose is an isomer of glucose. **3.5** Both store glucose as a complex carbohydrate, but plants store it as starch, and animals store it as glycogen. **3.6** Plants produce glucose through photosynthesis, but animals do not photosynthesize. **3.7** Cholesterol contains rings and both phospholipids and waxes contain long hydrocarbon chains. **3.8** Plant cells carry out more varied reactions (e.g., photosynthesis) than an animal cell does. **3.9** Proteins are made from the same amino acids in all organisms. **3.10** Globular proteins are enzymes present in all organisms, fibrous proteins are structural proteins, and plants do not use proteins as structural compounds. **3.11** The complementary DNA sequence would be CTAGGT. **3.12** The sugar in RNA is ribose not deoxyribose as in DNA; uracil in RNA replaced thymine in DNA; RNA is single stranded not a double stranded helix. **3.13** Yes, that's the only way a mutation can lead to an altered protein. **3.14** Plant cells absorb solar energy and produce glucose. Glucose in food leads to ATP buildup in cells. In muscle cells, ATP breakdown leads to muscle contraction and movement.

Form Your Opinion

Page 51: 1. Yes. Because of the increased instances of obesity, especially in children, it would be responsible for restaurants to decrease portion sizes. This change in the food service industry could help to reduce obesity and create a healthier overall population. No. People should be able to eat responsibly on their own. Restaurants should not have to manage the diets of their customers. 2. Due to the implication of cornstarch-based sweeteners and other ingredients in manufactured foods, manufacturers should be required to limit the use of such ingredients in their foods. Also, as required by the Food and Drug Administration, nutrition information should continue to be clearly printed on the labels of manufactured foods. Manufacturers could also monetarily support research into alternative sweeteners and healthier ingredients to create healthier products. It is also the responsibility of the consumer, however, to intake cornstarch-based sweeteners and saturated fats in moderation. **Page 55:** 1. Scientists are not called upon to judge whether a study is worthwhile; rather they are only concerned with its accuracy. Often, even studies with negative results precede a breakthrough. Studies should be encouraged as much as possible and considered worthwhile until evidence suggests otherwise. 2. Presently, we assume that evolution has a genetic basis and scientists will not be satisfied until they can point to the genetic cause of each evolutionary event. Studying whole organisms always leaves the genetic basis unknown. 3. Yes answer: By inserting a gene that allows tomato plants to thrive when watered with salty water, a genetic change has occurred within the organism. If the plants reproduce other genetically altered individuals, and a new population results, then evolution has occurred. No answer: This is an example of artificial evolution, and more appropriately, genetic engineering. Because the change was not the result of natural selection, it should not be termed evolution.

Testing Yourself

1. c; 2. c; 3. b; 4. b; 5. Like carbon, silicon has four outer electrons and can form four covalent bonds, as in SiO_2, the main component of sand. Carbon has two, but silicon has three, shells of electrons. Because of its larger size, silicon rarely forms chains, nor does it bond to four different types of atoms. 6. b; 7. a; 8. d; 9. c; 10. d; 11. c; 12. c; 13. Cellulose chains can form fibers because they lie side-by-side and hydrogen bonds form between them. The branching observed in starch makes fiber formation more unlikely. 14. a; 15. b; 16. d; 17. d; 18. c; 19. The hydrophilic heads interact with fluids, allowing the hydrophobic tails to orient toward each other. 20. c; 21. c; 22. d; 23. c; 24. d; 25. e; 26. a; 27. c; 28. Nucleic acid is a sequence of nucleotides and proteins are a sequence of amino acids.

Thinking Scientifically

1. a. Subject the seeds of temperate and tropical plants, for which you know the amount and kind of oil content, to a range of temperatures from above freezing to below freezing for an extended length of time. Plant the seeds and compare the percentage of survivals per type of plant. b. The presence of unsaturated oils in temperate plant seeds may be an adaptation to the environment. 2. Possible hypothesis: (1) The abnormal enzyme will not produce as much product per unit time as the normal enzyme. (2) The abnormal enzyme will have a different shape from the normal enzyme due to changes in organization.

Put the Pieces Together

Page 61: 1. Energy storage and use: lipids, which contain many energy-storing bonds; carbohydrates, which are a source of quick energy in the form of glycogen and starches. Genetic information storage: nucleic acids, like RNA and DNA which store genetic information in a sequence of nucleotides. Ongoing activities of the cell: proteins, which provide structure and support in the cell, speed chemical reactions, transport molecules (i.e., oxygen), and which are used in defense and regulation; lipids, which make up membranes, serve as hormones, and protect plants and animals in the form of waxes. 2. Just as the alphabet has only 26 letters and yet can produce many different words, DNA contains only 4 bases but the particular order of these bases in each gene can vary. This means that each gene specifies a different sequence of amino acids in each type protein. 3. I would expect each cell types to have its own particular combination of proteins.

CHAPTER 4

Check Your Progress

4.1 The parts individually cannot perform all the functions of a living cell. **4.2** Small cells have a larger surface-area-to-volume ratio and are better able to exchange materials. **4.3** Prokaryotic cells do not have a nucleus. **4.4** The electron microscope, not the light microscope, allows us to "see" this amount of detail, and the electron microscope was not available until the 20th century. **4.5** The eukaryotes: Nerve cells, onion root cells, and Euglena (a protist). Only eukaryotes, not prokaryotes (bacteria and archaea), have a nucleus. **4.6** First the ribosomal subunits, and then mRNA, pass from the nucleus to the cytoplasm, by way of the nuclear pores. They combine when protein synthesis begins. **4.7** Yes. Polyribosomes are in the cytoplasm. Other ribosomes are temporarily attached to the ER, and only the synthesized polypeptides enter the interior of the ER. **4.8** Synthesized polypeptides enter the interior of the RER, and some are incorporated into its membrane. The RER sends vesicles to the Golgi apparatus and the vesicles that leave the Golgi become incorporated into the plasma membrane. **4.9** Lysosomes combine with and digest microorganisms brought into the cell by vesicle formation. **4.10** Peroxisomes pass fatty acid breakdown products to mitochondria for further metabolism. **4.11** Lysosomes only digest; the plant cell central vacuole has storage and structural functions, as well as digestive functions. **4.12** Genes located in the nucleus code for the polypeptides that are produced by rough ER. The endomembrane system exports them from the cell. **4.13** Both are membranous organelles involved in energy transformations. They differ in that chloroplasts carry out photosynthesis and mitochondria carry out cellular respiration. **4.14** Interaction of actin filaments and microtubules with motor molecules. **4.15** The only anatomical difference is length; cilia are short and flagella are long. Cilia move like an oar, and flagella move in an undulating, snakelike fashion.

Form Your Opinion

Page 66: 1. I would give a friend the opportunity to see for his/herself by taking him/her into a biological

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laboratory and allowing them to examine a cell, for example, microscopically. 2. Color enhancement of TEMs does not border on misrepresentation because it is often necessary to enhance images to view and analyze them more clearly. However, I would encourage a side-by-side comparison of colored and non-colored TEMs images to show what a cell actually looks like. **Page 73:** 1. Carbon is present in all organic molecules but sulfur is unique to amino acids. 2. Palade may have also found the labeled amino acids on free ribosomes in the cytoplasm. **Page 77:** 1. The first cells to contain mitochondria and also chloroplast had an evolutionary advantage because they were more efficient energy users; therefore they could produce more offspring than other members of the population. 2. I would expect to find that both have membrane bound pigments capable of absorbing light energy. I would also expect to find that both have centrally located DNA. The cyanobacterium would be surrounded by a single membrane but the chloroplast is surrounded by a double membrane. The outer membrane is derived from the host plasma membrane.

Testing Yourself

1. c; 2. a; 3. c; 4. e; 5. d; 6. c; 7. d; 8. microscopically examine swab of skin; 9. b; 10. b; 11. c; 12. a; 13. The nuclear envelope has pores; transport vesicles; 14. d; 15. c; 16. c; 17. b; 18. anatomical and experimental data; 19. a; 20. a; 21. d; 22. Chloroplasts capture solar energy and form the carbohydrate broken down by mitochondria to produce ATP; 23. d; 24. b; 25. b; 26. c; 27. b; 28. a; 29. e; 30. d

Thinking Scientifically

1. Labeling RNA. You expect to find RNA in the nucleus, passing through a nuclear pore, and on RER. 2. Mitochondria have their own DNA and make their own proteins; therefore, they have RNA. The mitochondrial double membrane does not have any pores.

Put the Pieces Together

Page 83: 1. Prokaryotes are smaller than eukaryotic cells but they have DNA and ribosomes. Therefore, after being engulfed by a eukaryotic cell, they became what we call mitochondria and chloroplasts which are bounded by a double membrane and are capable of protein synthesis. 2. The folding of the endoplasmic reticulum creates a large area for the attachment of ribosomes outside and presence of enzymes for lipid synthesis inside. Rough ER, studded with ribosomes, is structurally equipped for protein synthesis while smooth ER, void of ribosomes, synthesizes lipids. The membranous nature of the membrane allows it to form transport vesicles. 3. The cytoskeleton assists in cell movement and serves to move items within the cell. These are functions consistent with the presence of microtubules in the cilia and flagella, structures used for locomotion and attachment.

CHAPTER 5

Check Your Progress

5.1 a. ATP represents potential energy; the energy is present in chemical bonds; b. Muscle movement is kinetic energy because motion is occurring. **5.2** Yes; any motion or cellular reaction that requires the breakdown of ATP increases entropy. **5.3** As long as cellular respiration is possible, ATP is constantly replenished by joining ADP with P. **5.4** Because ATP breakdown is coupled to the energy-requiring reaction of muscle contraction, the overall reaction increases entropy. **5.5** Each enzyme's active site allows only its substrate to bind. **5.6** The optimum pH gives the active site the correct shape to bind the substrate; body temperature increases the number of encounters between the substrate and the enzyme. **5.7** Inhibition of enzyme requires an abundance of a product and is easily reversed if the amount of product decreases. **5.8** Like the colored tiles, the proteins in a plasma membrane are different. But unlike the tiles, which are cemented in place, the proteins are free to move from side to side in the fluid phospholipid layer. **5.9** Channel proteins and carrier proteins. **5.10** Without water, organisms dry out and die. **5.11** A turnstile provides a way for only paying customers to pass through and the carrier protein provides a way for a molecule to pass through the plasma membrane if it can bind to the carrier. **5.12** Cholesterol accumulates in blood vessels where it can cause health problems. **5.13** Both plants and animals secrete substances that lie between the cells.

Form Your Opinion

Page 92: 1. Even though poisons can be ingested accidentally they should not be banned. Poisons are used to preserve foods, control pests, eliminate weeds, and to preserve buildings. Proper storage and use is important when using poisons, as well as posting notice when dangerous substances such as rat poison are present. 2. It might prove useful for countries to have poison detectors to provide warning in the event of a biological attack. Though the warning system may not be able to detect all poisons, it could save many lives if a system were in place to alert the public or a country's government of an impending attack. **Page 95:** 1. People could be convinced of the benefits of nutrition and exercise in the prevention of type 2 diabetes if shown case studies or other documentation of individuals with type 2 diabetes who have eliminated their disease through proper diet and fitness. Also, statistics correlating the poor eating and exercise habits of people with type 2 diabetes support the fact that this type of diabetes is the result of lifestyle and is preventable. 2. Versions of the text can be created for students with color blindness and other visual impairments (i.e., poor eyesight) for those individuals who would benefit from them. **Page 100:** 1. It seems reasonable that human and bacterial plasma membranes are the same when we consider that all organisms are descended from an original ancestor. All cells need a surface separating them from the outside world that is selectively permeable and capable of sending and receiving signals in order to support homeostasis. 2. The lack of a cell wall in animal cells is disadvantageous in that animal cells do not have the added protection and support provided by a cell wall surrounding the plasma membrane. Animal cells do have an extracellular matrix that can be quite hard as in compact bone. An extracellular matrix that can vary instead of a cell wall may have alowed animals to develop a greater diversity of cell types, tissues, and organs. Because of the development of nerves and muscles, animals gained mobility that is not found in plants and other organisms composed of cells with cell walls.

Testing Yourself

1. c; 2. a; 3. e; 4. d; 5. a; 6. Food in bulk is stored food in your pantry; glycogen is stored energy in the liver and muscles; meals provide only enough energy till you eat again; ATP is just enough energy for a reaction. 7. a; 8. e; 9. c; 10. b; 11. c; 12. b; 13. b; 14. b; 15. c; 16. d; 17. c; 18. Through osmosis solutes retain the liquid portion of blood in the vessels, allowing the blood to flow. 19. a, b, c; 20. b, c, d; 21. d; 22. b, d; 23. d; 24. e

Thinking Scientifically

1. Ecosystems need a source of energy because energy cannot be created. They need a continous supply because with each energy transformation, heat is lost; eventually, all the energy taken in is lost to the system as heat. 2. You need to decide the proper enzyme versus substrate concentrations, type of glassware, amount of time needed for the reaction, how to vary the temperature and the pH, and how to test for the product.

Put the Pieces Together

Page 103: 1. An enzyme serves to lower activation barriers by bringing reactants together within its active site. This is only possible due to the specific structure, or shape, of enzymes. The enzyme shape complements the shape(s) of the reactant(s), allowing them to interact chemically. 2. Polypeptide synthesis will not occur unless amino acids, enzymes, and the proper nucleic acids are present. Environmental pH and temperature must be appropriate. For any endergonic reaction to occur, ATP must be present to supply the necessary chemical energy. 3. Cell recognition glycoproteins, receptor proteins, and junction proteins found in the plasma membrane are all are involved in cell-to-cell communication.

CHAPTER 6

Check Your Progress

6.1 Plants can use the carbon dioxide and water from cellular respiration to carry on photosynthesis and produce food. **6.2** Thylakoids absorb solar energy because they contain chlorophyll; carbohydrates form in the stroma, because it contains enzymes. **6.3** NADH and ATP; $NADP^+$ and ADP + P **6.4** Warm weather allows enzymes to constantly remake chlorophyl. **6.5** Antenna molecules absorb energy and pass it to a reaction center. **6.6** The energy of motion, i.e., kinetic energy. **6.7** Water supplies electrons. NADPH is the final acceptor of electrons. **6.8** "Get ready": NADP reductase has received electrons, and a H^+ gradient is present. "Payoff": NADPH and ATP. **6.9** The Calvin cycle can take place in the light or in the dark. The Calvin cycle requires NADPH and ATP from the light reactions. **6.10** Glucose phosphate can react to produce sucrose, starch, or cellulose. **6.11** C_3 photosynthesis takes its name from first detectable molecule following carbon dioxide fixation in a plant cell. **6.12** Bundle sheath cells (the location of the Calvin cycle) are not exposed to the open spaces of a leaf where O_2 is located. **6.13** CO_2 is fixed at night but does not enter the Calvin cycle until the next day.

Form Your Opinion

Page 112: 1. The evolution of oxygen-releasing photosynthesis is an example of the concept of "adding on" rather than starting over in that photosystem II (PSII), which is necessary for the splitting of water to release oxygen, evolved after photosystem I (PSI) but did not replace it. 2. Cyanobacteria can revert to a cyclic electron pathway, using hydrogen sulfide (H_2S) as a hydrogen source to reduce carbon dioxide like other autotrophic bacteria. Chloroplasts cannot revert to using H_2S in place of water. **Page 118:** 1. Preserving tropical rain forests is advantageous because it protects and preserves the habitats of many of the plants and animals that can only be found in these forests while contributing to stable global temperatures. 2. Countries without tropical rain forests can assist in preservation through contributing money to conservation efforts, publicly supporting the protection of these dynamic ecosystems, and refusing to consume or use products that result from deforestation.

Testing Yourself

1. c; 2. d; 3. d; 4. c; 5. a. granum; b. thylakoid; c. O_2; d. Calvin cycle; e. stroma; 6. Only plants produce

organic food, and if animals only ate animals, food would run out. 7. a; 8. a; 9. a; 10 e; 11. d; 11. a; 12. a; 13. e; 14. b; 15. Solar energy is unable to participate directly in the chemical reactions that reduce carbon dioxide to carbohydrate, but ATP can do so. 16. d; 17. c; 18. a

Thinking Scientifically

1. Conditions have to be kept constant otherwise the result may not be due to a difference in the light provided. For a control, do the same experiment without elodea. 2. Photosynthesis takes place in leaf cells, showing that cells, and not organs, are the basic units of a plant.

Put the Pieces Together

Page 121: 1.Cyanobacteria gave rise to chloroplasts once they were taken up by a pre-eukaryotic cell, making them significant in the history of life as an integral part in the evolution of photosynthetic eukaryotes. These organisms are also credited with introducing oxygen into the atmosphere. 2. Using only words and arrows, the diagram based on Figure 6.7 should include all 11 steps; the diagram for Figure 6.9 should include the molecules listed in the upper box and all 5 steps. Eliminate the box in Figure 6.7 that represents the Calvin cycle reactions. Instead, stack your diagrams so that you can show how steps #8 and #11 in Figure 6.7 connect to steps # 3, 4, 5 in Figure 6.9. 3. C_4 photosynthesis is more advantageous to organisms (rather than C_3 photosynthesis) when the atmosphere contains significant amounts of O_2. C_3 photosynthesis was advantageous to the first photosynthesizers because the atmosphere didn't yet contain significant amounts of O_2.

CHAPTER 7

Check Your Progress

7.1 The oxygen we breathe in is necessary to cellular respiration which produces ATP. **7.2** It is a mechanism that allows oxidation to occur slowly so that more ATP are produced per glucose molecules. **7.3** Due to glycolysis 2 NADH and a net grain of 2 ATP have been produced. Some energy was lost as heat, and this heat can help warm bodies. **7.4** The reaction is getting ready for the Krebs cycle.The end product of the prep reaction (an acetyl group) enters the Kerbs cycle. **7.5** Per glucose molecule Krebs cycle accounts for 2 ATP directly and much indirectly because it produces 6 NADH and 2 FADH. **7.6** 22 ATP **7.7** "Get ready": H^+ gradient is established. "Pay off": ATP is produced. **7.8** Only glycolysis, because the other metabolic pathways occur in mitochondria. **7.9** Grapes are sometimes coated with yeasts that can start fermenting sugars (and producing alcohol) if the weather is conducive. **7.10** a. Hydrolytic reactions are catabolic. Dehydration reactions are anabolic; b. A hydrolytic reaction occurs when ATP breaks down to ADP + P (catabolic).

Form Your Opinion

Page 134: 1. The discovery that bacteria in addition to yeast ferment may have seemed irrelevant at first but it lead to the production of many products such as yogurt, pickles, and certain types of beer. 2. The products of this page do not negate that food is ultimately derived from plants. Fermentation is a process through which sugar is broken down in the absence of oxygen. Since sugar is produced by autotrophic organisms, namely plants, they play a large role in producing these products.
Page 136: 1. Statistical information on the correlation between illness and exercise would substantiate the claim that exercise can help to prevent a wide range of ailments. Evidence from studies on diabetics and cancer patients, for example, that showed higher instances of these diseases in individuals that do not exercise regularly, would support this claim. Since aerobic exercise burns fat, statistics that show higher rates of diabetes and cancer in patients with excess body fat would also support this claim. 2. Yes, evidence linking exercise to disease prevention would cause me to exercise more. Some diseases are genetic or result from exposure; however, if evidence shows that exercise is useful in warding off diabetes, heart disease, or some forms of cancer, I would find it beneficial to prevent those ailments that are avoidable.

Testing Yourself

1. a; 2. c; 3. b; 4. Glucose breakdown begins with glycolysis; oxygen becomes water at the end of the ETC; carbon dioxide is produced by the prep reaction and Krebs cycle. ATPs are produced by glycolysis (2 ATP), Krebs cycle (2 ATP per two turns), and 32-34 ATP by the ETC. 5. a; 6. e; 7. d; 8. b; 9. b; 10. c; 11. d; 12. d; 13. b; 14. Inner membrane space serves as an area where hydrogen ions collect before passing through an ATP synthase complex; b. Matrix is location of preparatory reaction and Krebs cycle; c. Cristae contain electron transport chain and ATP synthase complex. 15. Only 39% of available energy becomes ATP and the rest becomes heat. 16. c; 17. d; 18. c; 19. b; 20. b; 21. c; 22. Chloroplasts and mitochondria were originally independent prokaryotes. Prokaryotes evolved from a common ancestor, which must have used an ETC.

Thinking Scientifically

1. Acid, because for ATP to be produced, H^+ must flow through the ATP synthase complex.
2. The acetyl group that enters the Kreb cycle is oxidized to CO_2.

Put the Pieces Together

Page 139: 1. The pre-eukaryotic cell must have been a fermenter living off abiotically produced organic molecules. Cellular respiration couldn't have evolved until oxygen entered the atmosphere due to the evolution of photosynthesis. The eukaryotic cell became capable of cellular respiration after it engulfed a prokaryote that could carry out cellular respiration. 2. Structural similarities often point to evolutionary ties. Both the chloroplasts and mitochondria have an internal membrane system where various complexes are located. They both have a semiliquid interior where enzymes carry out carbohydrate metabolism. They both have an outer boundary that allows substances to pass into or out of the organelle.

CHAPTER 8

Check Your Progress

8.1 Abnormal because mutations can affect the normal structure of a chromosome. **8.2** Interphase because cancer cells spend all their time dividing. **8.3** Duplicated chromosomes contain sister chromatids and each one becomes a daughter chromosome. **8.4** Prophase-chromosomes are scattered; metaphase-chromosomes are aligned at equator; anaphase- daughter chromosomes are between equator and poles, telophase- daughter nuclei have formed. **8.5** A new cell wall in addition to a plasma membrane is needed for each daughter cell. **8.6** a. Loss of cell cycle control: lack of differentiation; abnormal nuclei; form tumors. b. Beyond loss of control: angiogenesis and metastasis. **8.7** Haploid, because each daughter cell receives one member from each homologous pair of chromosomes. **8.8** Sister chromatids have the same genetic information. Nonsister chromatids have genetic information for the same traits, but the specifics are different. For example, one sister chromatid could call for freckles, and the other could call for no freckles. **8.9** The chromosomes of relatives are more likely to carry some of the same genetic information. Therefore, fertilization may bring together like homologues. **8.10** Plant cells do not have centrioles or asters during both mitosis and meiosis. You can recognize meiosis by the pairing and separation of homologues during meiosis I. **8.11** In the haploid and alternation of generation cycles meiosis produces haploid spores that undergo mitosis to produce a haploid individual. **8.12** Meiosis I has the same phases as mitosis, but homologous chromosomes separate during prophase I. Meiosis II has the same phases as mitosis, but the cells are haploid. **8.13** An excess of genetic material would cause protein and metabolic abnormalities. **8.14** Meiosis II because the only way for YY to occur is through the nonseparation of chromatids during meiosis II. **8.15** No. For example, if the child inherited both chromosomes that participated in the translocation, one chromosome would be too short and the other would be too long, therefore the homologues for these chromosomes would look different in a karyotype.

Form Your Opinion

Page 147: 1. If bacteria make a protein similar to tubulin it does strengthen the hypothesis that bacteria contributed to the evolution of the spindle apparatus. 2. Evolution must necessarily make use of the structures and molecules currently available. For example the jaw evolved from the first two gill arches of jawless fishes; humans walk erect by standing on the hind legs of quadrupeds that preceded them.
Page 151: 1. Yes answer: If I had lived 75 years and was facing a diminished quality of life including memory loss, the inability to maintain personal hygiene, or eat and drink, I would be willing to risk cancer in order to correct Alzheimer disease. Even though cancer has its own problems, I would not want to lose the memory of my family, friends, and myself as I lived my final years. No answer: Though the possibility of cancer is not absolute, I would not be willing to risk spending the last years of my life being treated for, or dying from, cancer in order to cure Alzheimer disease. I would seek other treatments to slow the progression of Alzheimer disease and attempt to maintain my quality of life for as long as it may last. 2. Yes answer: A scientist should be able to patent independent work because our society now recognizes that a person has a right to his or her intellectual work. No answer: A scientist should not be allowed to patent intellectual endeavors because it is the custom for scientists to work together and share knowledge for the benefit of society.
Page 154: People who sunbathe, or drink or smoke cigarettes might be prone to follow the popular trend. They might feel that being one of a group engaged in these activities is worth it to them even though they may eventually die from them. You could give them examples of people who are popular even though they do not engage in these practices. 2. Because cancer does not occur immediately, the risk of cancer may seem unrealistic or too far into the future to be immediately relevant. However, having a friend or family member who has cancer, might make the illness more real to them.

Testing Yourself

1. a; 2. a; 3. a; 4. c; 5. a; 6. d; 7. c; 8. b; 9. c. 10. a. chromatid of chromsome; b. centriole; c. spindle fiber or aster; d. nuclear envelope (fragment). 11. c; 12. a; 13. e; 14. b; 15. d; 16. Due to crossing-over and independent alignment, that occurs during each meiotic event, the chromosomes in the egg and

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sperm carry different genetic information. 17. a; 18. d; 19. a; 20. e; 21. b

Thinking Scientifically

1. Both parents because the egg had to be missing this chromosome and the sperm had to have two of this chromosome. 2. While theoretically possible, it would be practically impossible to find two gametes with the exact same genetic information that produced this indiviudal.

Put the Pieces Together

Page 167: 1. The proximity of the homologous chromosomes during synapsis allows for the exchange of genetic information that occurs through crossing-over. Synapsis also allows for the alignment of homologous chromosomes during independent assortment. 2. In addition to crossing-over and independent assortment of chromosomes, the random fertilization that occurs through sexual reproduction results in increased variation among offspring.
3. As discussed in previous chapters, evolution is sometimes considered a process of "adding on" as opposed to starting over. Mitosis and meiosis being very similar events in which DNA is copied and passed on to a new cell, it is possible that a mitotic cell division gone awry was the first meiosis. For instance, a genetic defect occurred that allowed homologous chromosomes to pair by mistake during mitosis. Then, crossing over occurs between chromosomes, resulting in a new allele combination that benefits an organism. This "modified" mitosis which we call meiosis was passed on the next reproductive generation.

CHAPTER 9

Check Your Progress

9.1 The artificial selection of certain traits (controlled by genes) brings about recognizable breed changes. **9.2** Compared to dogs, pea plants are smaller, have a shorter maturation time, have traits that are easier to distinguish, can both self- and cross-pollinate, and produce many more offspring. **9.3** Hip dysplasia only occurs when offspring inherit two recessive alleles for hip dysplasia. **9.4** (1) a. RR b. Rr (2) a. all W; b. ½ R, ½ r; c. ½ T, ½ t; d. all T;(3) bb (4) 3 black rabbits: 1 white rabbit; 30 rabbits/120 are white. **9.5** TtGg, TTGG, TtGG, TTGg. **9.6** (1)RRPP, round seeds, purple flowers; (2) 75%; (3) 9:3:3:1, $^{1}/_{16}$; **9.7** (1) ¼; (2) Ss; (3) Tt x tt, tt. **9.8** Without careful records, the breeder may not know that all the individuals in row III are cousins who could carry the same recessive allele for, say, hip dysplasia. **9.9** Each parent is heterozygous. **9.10** Yes, if each were heterozygous. **9.11** The phenotypes of the potential offspring are: ¼ are normal; ½ may suffer a heart attack as young adults; and ¼ may suffer a heart attack in childhood. **9.12** Child: ii, mother: $I^{A}i$; father: $I^{A}i$, ii, $I^{B}i$; **9.13** (1) see Figure 9.13, page 183, in text. (2) Resistance is a polygenic trait with alleles on the X chromosome and chromosomes 2 and 3. (3) Diet is an environmental influence. **9.14** In CF, faulty chloride channels occur throughout the body and lead to problems in several organs, including the skin, lungs, and pancreas. **9.15** The Y chromosome is quite small. **9.16** (1) mother $X^{B}X^{b}$, father $X^{b}Y$, daughter $X^{b}X^{b}$; (2) $X^{R}X^{R}$, $X^{R}Y$; (3) (b); 1:1.

Form Your Opinion

Page 177: 1. The bulleted statements in the application show that the theory of evolution and the gene theory are compatible. When two theories are compatible it means that experimentation in one field supports the findings of another field as when two structures are supported by a wall they have in common. 2. Artificial selection allows us to reason that human beings are playing the role of the environment when natural selection occurs.
3. It worked because the phenotype is dependent upon the genotype. Darwin observed that the phenotype changes over time but Mendel deduced that the an organism has two factors (now called alleles) for each phenotypic trait. **Page 181:** 1. Testing either the 8-celled embryo or the egg prior to implantation is more acceptable than testing a child in utero and then terminating the pregnancy if the child tests positive for a genetic disorder. 2. IVF is acceptable to me, especially when used by people who struggle getting pregnant on their own. I do prefer testing the egg to testing the embyo because an egg will not produce a life without fertilization. Therefore, testing the egg and choosing not to use it cannot be considered termination of a life. However testing and disgarding an embryo that tests positive for a genetic disorder can be considered a termination of life.

Testing Yourself

1. c; 2. The blending model of inheritance results in no variations, whereas Mendel's model does result in variations among the offspring. Evolution requires variations. 3. d; 4. c; 5. d; 6. a; 7. a; 8. b; 9. It shows that a chromosome(and a chromatid) has a sequence of alleles; 10.a; 11 b; 12. c; 13. c; 14. b; 15. Egg testing because only eggs free of the faulty allele are fertilized. 16. e; 17.b; 18. a; 19. c; 20. e; 21. a; 22 d; 23.a; 24. $X^{A}X^{a}$.

Thinking Scientifically

1. Cross it now with a fly that lacks the characteristic. Most likely, the fly is heterozygous and only a single autosomal mutation has occurred. Therefore, the cross will be Aa x aa with 1:1 results. If the characteristic disappears in males, cross F_1 flies to see if it reappears; it could be X-linked (see Fig. 9.16). 2. Give plants with a particular leaf pattern different amounts of fertilizer from none (your control) to over-enriched, and observe the results. Keep other conditions, such as amount of water, the same for all.

Put the Pieces Together

Page 189: 1. Just as flipping a coin many times is more likely to give 50% heads and 50% tails so counting many F_2 is more likely to give a 3:1 ratio when the parent plants are heterozygous because the particular gametes that join with each fertilization is by chance. 2. Meiosis explains Mendels laws. Mendel's law of segregation holds because the homologous pairs separate during meiosis I. Mendel's law of independent assortment holds because either homologous chromosome of each pair of homologues can face either pole during metaphase I of meiosis. 3. Mendelian genetics laid the groundwork to eventually understand how genes function. Because of its many applications to human beings, Mendel's work allows us to understand the inheritance patterns of genetic disorders, including autosomal recessive and dominant disorders. Today, we can determine if parents are carriers for numerous genetic disorders and advise them of the chances they will pass on a particular disorder because of Mendel's laws.

CHAPTER 10

Check Your Progress

10.1 a. DNA contains deoxyribose, and the base T; RNA contains ribose and the base U instead of T. b. The particular sequence of the nucleotide bases. **10.2** DNA is a double helix in all organisms. **10.3** Complementary base pairing between the template strand and the new strand. **10.4** Transcription produces an mRNA molecule that is the same as the gene strand in DNA except that U occurs instead of T. mRNA splicing removes introns from mRNA and the introns removed can vary due to alternative mRNA splicing. **10.5** proline, tyrosine, arginine; **10.6** a. TAC in DNA = start codon in mRNA. b. ATT, ATC, or ACT in DNA = stop condons in mRNA; **10.7** The cell makes a protein by the process of transcription complementary base pairing with template strand and translation (tRNAs pair with mRNA codons)at a ribosome (rRNA). **10.8** A greater number of codons in mRNA and a greater number of amino acids would be incorrect.

Form Your Opinion

Page 197: 1. PCR should be used. Collection procedures should be standardized to eliminate the possibility of stray DNA entering the sample. Perhaps more than one lab technician could independently collect a sample and one of these technicians could be from an independent lab rather than a police lab. 2. Yes answer: Once a person has been convicted of a felony, it would make sense for their DNA fingerprints to remain on file in the event that another crime was committed. It would save time and money to already have this information readily available. No answer: Despite the fact that one crime was committed and a conviction made, there should be some degree of privacy with DNA fingerprinting, even for convicted felons. DNA fingerprinting can always be redone in the event of future crimes. 3. Yes answer: In the interest of science, public health and safety, PCR should be readily available. No answer: Government agencies like the Department of Health and Human Services could potentially regulate the use of PCR in instances where PCR would interfere with the privacy rights of an individual.
Page 205: 1. Transposons replicate within the DNA without regard to the consequences. DNA can be considered selfish because just as the most successful members of a population have the most offspring, the most successful DNA passes itself to the most members of the next generation without regard to consequences. 2. It is possible that P elements produced some evolutionary advantage in *Drosophila melanogaster* which was passed on via natural selection to spread into all populations of the species.
Page 206: 1. Yes answer: Health insurance should be fairly priced and affordable for all people. It is not guaranteed that sunbathers and smokers will get cancer and require extended medical care. No answer: Health insurance prices should take into account the likelihood that smokers and sunbathers will be sick and require long-term medical care for the treatment of diseases like cancer. Because there is a proven correlation between sunbathing, smoking, and cancer, it would make sense for insurance rates to be higher for people who choose these activities. 2. Yes answer: Bacterial response to mutagens can be relied upon as at least a predictor of human cell responses to these same substances. Though prokaryotes and eukaryotes differ, the Ames test can be used to indicate potential hazards and further testing could be conducted. No answer: Testing the effect of a mutagen on a prokaryote is not a completely reliable predictor of the response of a eukaryotic human cell to the same substance.

Testing Yourself

1. c; 2. e; 3. b; 4. a; 5. d; 6. c; 7. b; 8. DNA analogues prevent the formation of new DNA molecules, and each new virus requires a DNA molecule. 9. d; 10. b; 11. e; 12. a; 13. c; 14. b. 15. d; 16. d; 17. c; 18. b; 19. a. polypeptide b. amino acid c. tRNA d. anticodon e. codon f. ribosome; 20. c; 21. a. ACU CCU GAA UGC AAA; b. UGA GGA CUU ACG

UUU c. threonine—proline—glutamate—cysteine—lysine; 22. genetic information, in the sequence of its bases; 23. b; 24. b; 25. A change from ATG to ATA has no effect because both of the resulting codons code for tyrosine. 26. Without mutations, new adaptations cannot occur and new life forms cannot evolve.

Thinking Scientifically

1. Determine if any transposon base sequence occurs in the sequence for the neurofibromatosis gene.
2. Place the isolated gene in *Arabidopsis* cells and look for the mutation in cloned adult plants.

Put the Pieces Together

Page 209: 1. The criteria for a genetic material: (1) it must be variable, accounting for the differences between species. DNA is variable. Differences in the base pairing combinations found in DNA molecules produce differences in proteins, which account for the variation between species; (2) it must be able to replicate, as DNA does, in a semi conservative process by which it duplicates itself; (3) it must be able to undergo mutations. DNA undergoes mutations, another factor which accounts for variability in organisms. DNA can undergo mutations during the replication process, due to contact with external factors like radiation, or due to random events like jumping genes, or transposons, which in turn alter gene expression and cause many changes in organisms. 2. This suggests that protein-coding genes in specialized cells may be activate or inactive at different points in the cell's life. 3. Futuristic drugs might affect the early synthesis procedure, changing or eliminating the proteins to be produced by making changes in mRNA before it reaches the ribosomes.

CHAPTER 11

Check Your Progress

11.1 Regulatory genes code for DNA-binding proteins. **11.2** Transcription factors and transcription activators. **11.3** Inactive means that the DNA is not being transcribed; heterochromatin means that the chromatin is tightly packed. **11.4** Because *Pax6* could not be present in so many different animals unless they are related through evolution **11.5** Introns are removed during processing. **11.6** miRNAs lead to limited amount of mRNA translation while siRNA lead to no translation of mRNA **11.7** Translation repressor proteins can prevent translation of mRNA; enzymes may have to cleave a protein to activate it; tagging of a protein makes it vulnerable to digesion inside a proteasome. **11.8** a. transcription factor b. euchromatin c. introns removed d. RISC e. proteasome **11.9** a. Cell cycle keeps going when it should stop. b. The gene is now coding for a faulty protein in an inhibitory transduction pathway. **11.10** Cancer is caused by a series of mutations and all these mutations may or may not occur.

Form Your Opinion

Page 217: 1. Yes answer: The brain is a fascinating organ about which scientists, doctors, and everyday people have many questions. The more avenues we explore to help answer these questions, the more headway we might be able to make in matters involving the brain, such as Alzheimer disease or human intelligence. Evolutionary changes in the brain and its development might serve to teach us much more than we could ever imagine. No answer: Research should focus on the human brain alone and how it works. There is no guarantee that looking into the differences between human and ape brains will give us any relevant or useful information. 2. This reading tells us that our brain continues to develop after we are born and this accounts for its large size. It suggests that coordination between brain parts and the functioning of limbs was sacrificed to this enlargement. 3. Yes, it does make sense. Initially, cells divide to make exact copies of themselves which serves to produce a larger organism. As the cell number grows, regulatory genes bring about differentiation of cell types so that they perform different functions. Without this specialization, cell division would simply create copy after copy of the original cell and development of an organism would not occur. A human-sized clump of cells and a human being differ greatly due to specialization through regulatory genes.
Page 224: 1. Yes answer: By making a young person aware that they could carry a cancer gene, they can make informed decisions about life, including screening to detect cancer early and often to potentially treat it as soon as it appears. A young person might lead a healthier life to help ward off illness with exercise and a proper diet. An informed person may also decide, based upon knowing the probability, whether or not to have children and potentially pass the gene along. No answer: Making a young person aware that they could carry a cancer gene could potentially make the person's life miserable with paranoia and trips to the doctor for every ache and pain. A person may decide against having a family, participating in activities that expose them to sun or other carcinogens, and lead a depressing and anxious life. I think the choice to find out if you could carry a cancer gene should be made by each person individually. 2. Yes answer: Especially when there is a family history of cancer, the testing can help doctors catch and treat the cancer earlier, and advise the patient on the healthiest life possible to avoid the cancer. Decisions can also be made regarding reproduction and passing the alleles to children. However, just because the testing for cancer-causing alleles should be advised, it should be voluntary. All people are different and some individuals may not want to know every last detail about their future health.

Testing Yourself

1. a. DNA; b. regulator gene; c. promoter; d; operator; e. active repressor; 2. b; 3. b; 4. b; 5. d; 6. b; 7. b; 8. b; 9. b; 10. c; 11. e; 12. e; 13. d; 14. a; 15. c; 16. b; 17. Benefit is refinement of control; drawback is more chances of losing control; 18. b,c; 19. a,c; 20. a,d; 21. a,d; 22. c,d,a,b

Thinking Scientifically

1. You should also show that the genes having homeoboxes result in similar developmental stages.
2. Culture normal cells in the presence of the pollutent and observe the results. Culture the same types of cells in the same manner but without the pollutent and observe the results.

Put the Pieces Together

Page 227: 1. Many of the anatomical differences between apes and humans pertain to differences that might have arisen due to a change in gene regulation. For example differences in brain development and infant strength could be due to particular protein activities during development. 2. A knowledge of regulation can be used to understand the onset and progression of diseases, particularly those that result from genetic mutations that effect protein production. With an understanding of how regulation turns protein production "on" and "off" we might discover methods to artificially "flip the switch" to head off potentially detrimental changes in protein levels. 3. Genetic regulation is to cells as a teacher is to a class room. The students (cells) need clear instructions on what tasks to perform (when protein production is needed) or chaos (disease) will result.

CHAPTER 12

Check Your Progress

12.1 The nucleus contains the genes that determine the phenotype. **12.2** The GFP gene only causes living organisms to glow in dark. **12.3** Genes function the same in all organisms. **12.4** By cloning you're assured of producing only females that produce milk. **12.5** A virus **12.6** How the pieces should be sequenced. **12.7** a. introns, unique and repetitive b. repetitive DNA is the largest portion and investigators are determining if it has a regulatory function. **12.8** a. You would know what proteins are made by specialized cells and why some cells malfunction. b. Bioinformatics can find similarities and differences between proteomes, for example.

Form Your Opinion

Page 231: 1. Reproductive cloning can help to preserve rare animals that might otherwise become extinct. It can also provide a large number of agricultural plants for farmers. Once an animal has been genetically modified for a particular purpose, it can produce other animals with the same genotype and phenotype. Reproductive cloning also helps the scientific community increase its knowledge of gene interactions and embryonic development. 2. Yes answer: Reproductive cloning has many potential side effects that are less than desirable. Because we do not completely understand and cannot predict the possible hazards of cloning animals and human beings, I find the process to be risky and potentially dangerous. Animals and people can be created that suffer from premature aging and disease, or worse, a person with uncontrolled aggression or mental imbalance. If this occurs, we have created a life that will cost money to diagnose and treat or poses a danger to itself or others. There are also religious and moral issues regarding the production of life. No answer: When used to preserve endangered species I find the cloning of animals to be a useful procedure. Also it can help populate the world with humans, animals, and plants that have a beneficial genotype and phenotype. 3. Because the harvesting of stem cells from embryos creates controversy over moral issue, I think that we should explore therapeutic cloning using adult stem cells and treated skin cells since this method is already in the works and is less controversial for the general public.
Page 235: 1. Based on the ability of scientists to perform simulated digestion of GM crops using enzymes to test for the characteristics of allergens, as well as feeding the GM crops to test animals like rats, it seems that scientists have the ability to decide pre-market if a GM crop is potentially harmful. 2. Yes answers: Because of the unpredictable risks and the newness of the technology, I am in favor of banning GM crops until long-term studies have informed scientists on the long-term effects of consuming these foods. And I do approve of ecoterrorists burning crops and destroying labs that could potentially be harmful to the public. Getting rid of the crops and the labs they are genetically engineered in slows the spread of GM crops to the market and protects the public from what might create health problems in the long-term. No answer: I do not favor a ban of GM crops. GM crops have increased yields, decreased losses due to herbicides and pests, and have been tested before hitting the shelf. I do favor the proper labeling of such crops and the decision to consume these or other crops being left up to the consumer. And I do not approve of ecoterrorism or the burning of crops and labs that could be useful in scientific research. Boycotting GM

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products or informing the public in peaceful displays would be desirable alternatives to destroying crops and property. 3. If a genetically modified food can provide an otherwise lacking vitamin, it should be used where it will benefit the people and prevent childhood blindness. Data on any side effects of the GM rice and whether or not they outweigh its benefits would help in decisively banning or allowing the public consumption of GM rice enhanced with vitamin A. **Page 242:** 1. Yes, I would have expected gene regulation to account for major evolutionary differences because the control of protein production results in the different characteristics we see between species. The types and amount of proteins being produced by an organism determine important attributes like appearance and development. It makes sense then, that control of protein production accounts for differences among the species. 2. Yes answer: If a study of my genome and the diseases prone to others with similar genetic make-up might lead to beneficial findings for other human beings, I would be willing to participate in a comparative human study. No answer: I think that genome studies should rely on testing plants and approved animals. The privacy of human subjects is at risk in comparative studies and I would prefer to preserve my privacy rather than participate in a study that exposes my genetic weaknesses. 3. Since we are not identical twins, I would expect my genome to differ slightly from my siblings. Though we have a great deal in common, there must be differences in our DNA because we are all different people.

Testing Yourself

1. b; 2. a; 3. a; 4. d; 5. e; 6. c,a,b,d; 7. c; 8.e; 9. begins: AATT; ends: TTAA; 10. a; 11. a; 12. e; 13 Plants and animals can trace their ancestry to a common source, and therefore plants are able to express a human gene. 14. a; 15. c; 16. d; 17. e; 18. Genetically modified stem cells pass on their modification to their offspring (more white blood cells) indefinitely. 19. b; 20. c; 21. a; 22. Each gene performs only one function, so despite increased number of genes, only 30 gene functions would be available. 23. a; 24. d; 25. d; 26. c; 27. d; 28. a; 29. c

Thinking Scientifically

1. Use restriction enzymes to fragment the DNA of chromosome 10. Inject these fragments, one at a time, into groups of one-celled mouse embryos. Following development, see which mice have no tails. 2. An ex vivo study allows you to perfect your procedure in the lab and possibly avoid harm to the patient.

Put the Pieces Together

Page 245: 1. Biotechnology takes what we know about nature and utilizes developments in technology to artificially produce desired results for human beings. Because of the blending of science and technology, biotechnology is aptly named. 2. (1) Our cells contain many more proteins that there are genes that code for proteins. (2) Introns may help regulate the number and kind of exons in each type protein. (3) Repetitive DNA is translated into RNA and it appears that several types of small RNAs are involved in both transcription and translation. 3. To the layperson, biotechnology and genomics may appear to be tampering with nature and playing "God." Many of the procedures and technologies associated with biotechnology might seem extreme to the layperson, or difficult to understand. If portrayals in movies are the only source of information regarding cloning and other biotechnology, the layperson may believe that scientists are "evil" and science itself as unregulated and self-serving.

CHAPTER 13

Check Your Progress

13.1 Darwin made observations that would help him formulate a hypothesis. **13.2** No, you would pollinate it by hand with the pollen of your choice. **13.3** Any plant that provided food (nectar) to a particular pollinator had an advantage that resulted in more offspring than other members of the population because its pollen was being distributed. **13.4** Yes. Whenever independent sources come to the same conclusion based on the data they have collected, the hypothesis is supported. **13.5** Flowers are delicate and decompose quickly, not allowing time for them to become fossils. **13.6** The flowers would have shorter and thicker floral tubes. **13.7** The flowers probably had a common ancestor. **13.8** These species of finches evolved on the Galápagos Islands. **13.9** All organisms are related through common descent from the first cell or cells. **13.10** Genetic similarity maintains the characteristics of the species; genetic variation allows evolution (adaptation) to occur. **13.11** Microevolution has occurred when allele frequency changes are observed due to mutations, gene flow, nonrandom mating, genetic drift, and natural selection. **13.12** Yes; any flower mutation that increases the chances of being pollinated and any mutation in the pollinator that increases the chances of getting food results in more offspring with the same adaptation. **13.13** Imagine a pollinator that only pollinates a particular species and can only see flowers of a certain color. Only flowers of that color would produce seeds, and soon all flowers of that species would be that color. **13.14** Yes, because genetic drift causes a change in allele frequencies, but does not necessarily contribute to adaptation. **13.15** Yes, because a flower of any other color has little chance of being pollinated. **13.16** Yes, because, in this instance, natural selection favors the heterozygote. Natural selection favors whichever genotype/phenotype is most advantageous in a particular environment.

Form Your Opinion

Page 254: 1. The now common occurrence of MRSA (methicillin-resistant Staphylococcus aureus) is an example of antibiotic resistance that many people now know about. Many patients think of antibiotics as a universal cure for all ailments and pressure doctors into prescribing them. However, physicians should stop overprescribing antibiotics and patients should be sure to take all doses that were prescribed. Also instead of increasing pesticide use or changing pesticides, farmers should set aside farmland that encourages the reproduction of non-resistant insects. If a farmer can increase the number of non-resistant insects on their land, lower levels of pesticides will continue to eliminate these insects. Current practices call for the increased use of pesticides and development of new ones as resistant insects rise in population. 2. Due to extent of human involvement, drug development, design, and improvement is artificial selection for the best drugs, but not natural selection at work.
Page 262: 1. A taste for sweet foods in humans, apes and monkeys benefits plants containing sweet proteins because the more these plants are ingested, the more widely the distribution of their seeds in the waste of humans and animals. The spreading of these seeds over larger areas and at high rates gives the plants a reproductive advantage over plants that are not eaten as much. 2. Humans are influencing the evolution of plants when they propagate them. When humans step in to produce more of one plant than another, for food or other purposes, they are artificially selecting for some plants to have more reproductive success than others. When humans genetically modify and breed plants, they certainly influence the plants' evolution. Changing something about the plant, which would only occur over time due to mutations and natural selection in nature, at least speeds the evolutionary process—that is, if the genetic modification made by humans would occur in nature at all. Any human involvement in plant reproduction or genetic composition influences evolution. The engineered plants humans create may evolve entirely differently than non-engineered plants would have. 3. Artificial selection can be harmful to plants and animals because it (1) reduces variation and (2) can make organisms prone to disease and (3) can select for traits that do not help the animal survive in the wild.

Testing Yourself

1. b; 2. c; 3. c; 4. d; 5. b; 6. Neither the occurrence of mutations nor the changing of environmental conditions are known ahead of time. 7. e; 8. d; 9. e; 10. e; 11. a; 12. d; 13. c; 14. b; 15. Their DNA base sequences were inherited from a common ancestor. 16. a; 17. a; 18. c; 19. d; 20. b

Thinking Scientifically

1. If you know the genotype of the various colors, you could use the Hardy-Weinberg equation to calculate changes in gene pool frequencies. Otherwise, you could base sequence before and after the experiment to determine a change in the genome. 2. Yes; due to natural selection of boll weevils resistant to the insecticide.

Put the Pieces Together

Page 269: 1. Evolution via natural selection can be witnessed, particularly in organisms that have short life cycles and thus reproduce multiple generations over short periods of time. For example, over 5 years silent male field crickets increased from 10% to 90% of the population in a study conducted in Hawaii. The silent cricket had an advantage over the chirping cricket in its inability to be detected by a predator. This selective pressure caused silent crickets to survive to reproduce while chirping crickets were preyed upon. Other examples can be seen in the evolution of pesticide-resistant insects as a result of the increased use of pesticides and antibiotic-resistant bacteria due to the selective pressure of increased antibiotic use. 2. We expect evolution to have a genetic basis because genes control the phenotype of an individual including structural, metabolic, and behaviorial traits. Thus genetic changes had to precede the observation of phenotypic changes. 3. Because evolution is not directional, it would be incorrect to say that bacteria became resistant in order to escape being killed by antibiotics. The mutations that allow bacteria to become resistant had to have occurred before they were exposed to the antibiotic. Nature selected *for* resistant individuals and *against* the non-resistant.

CHAPTER 14

Check Your Progress

14.1 No, because ligers share the ancestry of both lions and tigers, and they do not ordinarily occur in the wild. **14.2** a. Habitat isolation; lions live on the plains, and tigers live in forests; b. F_2 fitness; ligers are usually sterile (due to mispairing of chromosomes during meiosis). **14.3** Members of the ancestral species separated into those that lived on the plains and those that lived in the forest. Over time, each became adapted to its habitat, including a change in coat color. Now, lions and tigers do not mate because they rarely come into contact, and also because the coat color allows them to recognize members of their own species. **14.4** You need

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evidence that each of the cats is adapted to fill a different niche. **14.5** The fossil record would have to show fossils of the different types of cats existing in the same location at the same time—before they begin to appear in various locations. **14.6** A gradualistic model if the ligers are transitional links. **14.7** a. Ligers are larger than either parent. b. The large size of ligers is an advantage that is selected for. **14.8** No, evolution is not goal oriented.

Form Your Opinion

Page 280: 1. Yes answer: We should continue to convert corn to ethanol. Despite increased cost of corn, we must produce alternative energy sources in order to reduce our reliance on non-renewable resources. Since eventually we will have no choice but to use alternative methods, it is best that we explore those we have already developed, including the conversion of corn to ethanol. It is possible that the increased cost of corn could be offset by the decreased need for expensive petroleum-based fuels. No answer: We should not continue to convert corn to ethanol if it raises the cost of corn needed to feed humans and animals around the world. We should explore other alternative fuel methods and temporarily maintain our reliance on petroleum while we still have it. We must develop alternative methods for energy, particularly those that are more efficient and less disruptive than converting corn to ethanol. 2. Yes answer: We should grow more corn for energy production through conversion to ethanol and use less in the process of creating waste and feeding beef. This might lead to limited beef in human diets and less waste to dispose of, solving problems associated with pollution of ground water, circulatory problems in humans, and even obesity in our fast-food fed nation. If corn was primarily grown to produce energy, we might explore alternative foods for animals and humans alike. No answer: We should not grow more corn for ethanol conversion and decrease its use as food for humans and animals. We should develop better waste management practices and moderate our consumption of beef while continuing to use corn for food. If we can grow more corn, this is not an either/or situation and we can have enough corn for ethanol production and food uses.
Page 283: 1. Since science seeks to answer questions about the natural world, the scientific community should use phenomenon like the Burgess Shale to help answer these questions. Since fossil evidence can help to fill in blanks in evolutionary history, the fossils should be examined and evaluated in an attempt to figure out how they fit into the story of our planet. The scientific community should do its best to preserve such phenomenon while objectively examining the history hidden inside. Potentially detrimental "shots in the dark" should be avoided and in some cases, samples should be preserved until technology can be developed to meet the demands of dissecting fragile fossil evidence. 2. Students should be presented objective information about the unexplained. This can encourage students to understand the progressive nature of science, along with how much we do not know about the world in which we live. Exposure to phenomena that is yet to be fully explained can help students understand the scientific process. These students may someday be scientists themselves, developing techniques or technology that will help us learn more about these phenomena.

Testing Yourself

1. c; 2. c; 3. b; 4. f; 5. a; 6. e; 7. h; 8. e; 9. c; 10. e; 11. Genetic differences; 12. a. species 1; b. geographic barrier; c. genetic changes; d. species 2; e. genetic changes; f. species 3. 13. d; 14. b; 15. Allopatric speciation was possible on the Hawaiian Islands, but not on the Florida Keys. 16. b; 17. c; 18. d; 19. b; 20. b; 21. c; 22. b; 23. d; 24. b; 24. d; 25. Hox genes evolved early in the history of life. 26. d; 27. b

Thinking Scientifically

1. The evolutionary species concept allows you to trace the history of an organism in the fossil record, and the biological species concept provides a way to identify species without the need to examine them anatomically. 2. Their chromosomes are compatible, and the two species are very closely related. It's doubtful they should be considered different species.

Put the Pieces Together

Page 289: 1. Biologists have made testable hypotheses about (1) the activity of *Hox* genes in many different species; (2) the effects of regulatory genes on developmental processes; (3) the need for geographic and reproductive isolation in order for a new species to arise; (4) the role of polyploidy in the origination of new plant species and (5) the role of gradualist and punctuated equilibrium models in speciation. 2. Paleontologists suggested the punctuated equilibrium model using data from the fossil record that supports the sudden appearance of new species. These species then undergo little morphologoical change until becoming extinct. 3. Yes, the study of evolution is a scientific endeavor. In order to understand the process of evolution, scientists have formulated hypotheses and tested these hypothesis in the natural world. This has resulted in the collection of data and a conclusion that evolution does occur. Natural selection can be used to explain observations in other fields of biology from genetics to behavior.

CHAPTER 15

Check Your Progress

15.1 When tracing the evolution of life, you need to start with the past and move toward the present. The dates are in MYA; therefore, the larger numbers in the timescale are more distant from the present than are the smaller numbers. **15.2** Yes, because dinosaurs evolved at the start of the Mesozoic era, when the continents were all still joined. **15.3** Humans didn't evolve until the Holocene epoch, long after the last mass extinction. The possibility exists that humans could become extinct due to their own activities. **15.4** Only plants that resemble virgina creeper are in the same genus. Domain Eukarya contains the plants, animals, fungi, and protists. **15.5** Animals share the same way of life; they are all motile and ingest their food. **15.6** Monkeys and gorillas share a more recent common ancestor than do reindeer and gorillas. **15.7** epidermal scales **15.8** Yes, dinosaurs being vertebrates share the homologous structures of vertebrates.

Form Your Opinion

Page 299: 1. In some instances the ability to readily identify any species of organism could be beneficial to society. In fields such as farming, education, and medicine this technology would prove particularly useful for identifying organisms that propose a threat to plants and/or human beings. For example, a farmer, doctor, or student could differentiate poisonous or otherwise harmful insects or plant species that differ only subtly in appearance from non-harmful species. This could assist in medical diagnostics for rashes, insect or snake bites if some portion of the organism were available for identification. Because of the need to scan either the organism or a portion of it, the ability to identify a species may not always be possible, however. 2. The conversion of the CBOL methods to a criminal identification process would most likely require the isolation of definitive nucleotide sequences that differ between individuals or would otherwise require the sequencing of a person's entire genome. It could potentially work through inserting a sample of hair, blood, semen, or skin into a scanning device. Individuals could be required to have their DNA sequenced upon birth, arrest, or medical care such that a catalog of DNA could be used as a reference for comparison of the scanned genetic material, much like the catalog that exists for organisms that have been sequenced by scientists. 3. Yes answer: I would try to make money from human bar-coding, as should individuals involved in developing this procedure. If the technology was developed to bar-code to the level of identifying individual people, it should be marketed for a profit. Scientists and inventors alike should be able to earn a living from the procedures and technology that they spend time developing, testing, and improving. No answer: I would not try to make money from human bar-coding technology and the individuals involved should not try to sell their procedure for a profit. It would make sense for individuals involved to be compensated for their work but not to profit. Selling procedures to the highest bidder puts science beyond the reach of everyday people, who should have just as much access to scientific development as more affluent individuals.
Page 302: 1. Cladistics is considered more objective than evolutionary systematic because it presents its data for all to see and no conclusions are subjective. This is why cladistics has most likely been welcomed and will continue to be well received by the scientific community. 2. Science should be willing to change while still retaining traditional methods that are also useful. We should particularly keep any traditional methods have been well tested. Innovation, however, propels science forward and is only natural in a field driven by hypotheses and experimentation.

Testing Yourself

1. b; 2. d; 3. a; 4. c; 5. e; 6. e; 7. a; 8. d; 9. d; 10. a; Ferns; b. produce seeds; c. naked seeds; d. needle-like leaves, Conifers; e. fan-shaped leaves, Gingkos; f. enclosed seeds; g. one embryonic leaf, Monocots; h. two embryonic leaves, Eudicots. 11. b; 12. d; 13. e; 14. b; 15. e; 16. b; 17. New and different stuctures arise due to DNA differences. 18. b; 19. a, b, c; 20. d, e; 21. b; 22. The three-domain system is based on differences/similarities in the sequencing of rRNA. This is backed up by differences in structure.

Thinking Scientifically

1. The tree shows that all life forms have a common source and how they are related, despite the occurrence of divergence, which gives rise to different groups of organisms. 2. The specialized environmental niche of these organisms is the same as it was when they first evolved.

Put the Pieces Together

Page 307: 1. Yes answer: Putting the biosphere and all of its organisms into a tree of life would put the vast nature of the world in perspective and would make me want to preserve all species now alive. No answer: The overwhelming nature of a complete tree of life might decrease my interest in the preservation of species by sheer over-stimulation. Seeing that so many species exist, some being very similar to one another might detract from the value of each species individually. 2. Yes answer: I do look forward this because determining the ancestry of humans all the way to the first living source is an exciting concept that seems to fit naturally into the human desire to understand who we are and where we came from. No answer: I do not look forward to tracing the ancestry of humans to the very first living source and do not trust the data that traces

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the ancestry of humans to the first living source. 3. It does not surprise me that humans are related to all other organisms on the planet. An understanding of genetics and evolution helps explain why connections exist between all living organisms. Also, the shared characteristics of all living things (see page 18) help to support the undeniable interrelatedness of every organism, past and present.

CHAPTER 16

Check Your Progress

16.1 The genes become incorporated into the virus's nucleic acid core. **16.2** The virus should be lysogenic and should never undergo the lytic cycle. **16.3** Only plant cells have receptors for plant viruses. **16.4** To avoid unintentionally infecting the researcher. **16.5** DNA animal viruses do not carry out reverse transcription and integration. **16.6** As yet, there were no enzymes to allow reactions at mild temperatures to occur. **16.7** a. RNA can store, replicate, and transmit genetic information; b. RNA can perform enzymatic functions, including those for replicating itself. **16.8** a. Proteins (enzymes) allow a cell to acquire energy and grow; b. Genetic information (either in the form of RNA or DNA) is needed for reproduction. **16.9** The capsule protects bacteria from the host defenses, and the pili help bacteria adhere to parts of the human body. **16.10** Binary fission will quickly produce a large number of bacteria, which will all have an ability to feed on oil. **16.11** During sexual reproduction, each parent passes a complete copy of its genome to an offspring. During transformation, conjugation, and transduction, a fully formed bacterium receives a few genes from another fully formed bacterium. **16.12** a. All humans require oxygen and bacteria differ in their need for oxygen; b. All humans are heterotrophs and bacteria can be photosynthetic, chemosynthetic, or heterotrophic. **16.13** Cyanobacteria are believed to be the first organisms to release oxygen into the atmosphere. Cyanobacteria still release oxygen, just as algae and plants do. **16.14** Bacteria and archaea arose from a common ancestor; eukaryotes arose from archaea. **16.15** Bacteria are saprotrophs whose digestive enzymes break down materials in the environment.

Form Your Opinion

Page 313: 1. The special concerns associated with catching a newly discovered emergent disease include the potential of catching a new strain that cannot be treated or cured in the same manner as previous strains. A new disease may not be diagnosed and treated properly. 2. It is both a service and disservice for the media to publicize emergent diseases to the level that they do. It serves the public to be informed and take precautions to avoid infection. It does not serve the public to be worked into frenzy over worst-case scenarios that suggest the world may be coming to an end. 3. We are probably unnecessarily accusatory. A country cannot be exclusively blamed for being the origin of a disease due to factors that are largely out of the control of that country's people. It would benefit the entire world if we helped developing countries by campaigning for and helping to implement programs for clean water, good hygiene, and medical care in order to prevent the spread of disease.
Page 316: 1. Hypothetical evolutionary stages between the first viruses and bacteria might include intermediate stages. 1) It would be necessary for the virus to independently carry out protein synthesis Since a virus already has either RNA and DNA, they would only need to acquire both at the same time. In fact some RNA viruses even now carry out reverse transcription in order to form DNA. A virus could also take for itself some of the DNA from a host cell. With the ability to produce enzymes, cellular respiration would be a possibility. Now the virus could live independently. 2) The virus would need to gain a plasma membrane and this may have happened by keeping a portion of the plasma membrane of the host cell. 2. If the viruses of today are degenerate forms of viruses that gave rise to cells, their parasitic life style may have caused them to lose certain abilities out of disuse. In their degeneration, viruses of the past would have lost the ability to replicate independently, carry on metabolic activity independently, and thus to live outside of a host cell. 3. A parasite needs to produce a sufficient number of offspring so that some will go on to parasitize other hosts. Many offspring are expected to never find another host; the greater the number of offspring the more likely a new host will be infected.
Page 327: 1. I would explain the symptoms of gonorrhea, including pain with urination, bloody or milky discharge, pelvic inflammatory disease (PID), reduced fertility, tubal pregnancy, blindness in infants who pass through an infected birth canal, and possible spread to internal organs leading to heart disease or painful arthritis. I would also stress the many ways in which gonorrhea can be contracted and parts of the body it can infect, including the eyes, mouth, throat, and tonsils. The two most important points I would raise are that the risk of contracting HIV is increased when a person has gonorrhea, and that it is possible that some strains of gonorrhea will be incurable with antibiotics if this bacteria continues to evolve new strains, increasing the risk of permanent side effects when major organs are infected. 2. Children should be instructed about gonorrhea early, in late elementary to early middle school years. Just like other diseases, it is important to inform children about the risk of and precautions against sexually transmitted infection. The earlier the instruction takes place, the greater the chances that infection can be avoided instead of having to be treated. Teaching children to be responsible, even in matters that might make parents and other adults uncomfortable, provides them with the information they need to be safe and healthy.
Page 328: 1. No answer: If we discontinue flyovers, bioterrorists would certainly just find another method to attack with. We should take precaution to control air traffic during sports events and not discontinue activities in fear of possible attack. Yes answer: Bioterrorists might take advantage of the gathering of a large crowd and the fact that a flyover is not an abnormal event during a sporting event. Discontinuing flyovers may prevent a catastrophic attack using biological weapons. 2. Yes answer: Though the Unites States should not retaliate with biological weapons, it has a responsibility to retaliate and defend its people in the event of a bioterrorism attack. No answer: The United States should not retaliate and perpetuate a cycle of destruction using biological weapons, which pose a threat to all living things and has potentially unknown and far-reaching side effects.

Testing Yourself

1. c; 2. e; 3. c; 4. d; 5. b; 6. a. Lytic cycle: the virus is immediately produced and can go on to infect other cells. In life cycle b. Lysogenic cycle: the virus is being replicated along with the host cells and is protected from exposure to host defenses. 7. c; 8. c; 9. c; 10. a; 11. e; 12. b; 13. c; 14. c; 15. a; 16. c; 17. b; 18. e; 19. a; 20. b; 21. a; 22. d; 23. b

Thinking Scientifically

1. Viruses replicate inside human cells, and therefore, medications aimed at a virus can interfere with the workings of human cells. 2. The bacterium *E. coli* has the same genetic machinery as all other cells, including eukaryotic cells. They reproduce quickly and a large number can be kept in a small container. Since bacteria are haploid, mutations can be immediately observed.

Put the Pieces Together

Page 331: 1. Not all bacteria cause disease. There are bacteria present in a healthy digestive system, in foods including yogurt and cheeses, and in food and beverage production processes like fermentation in bread and alcohol. 2. The first stages of the scenario described in figure 16.7 can be explained using the iron-sulfur world hypothesis through which thermal vents in the ocean could have heated water containing iron and nickel sulfides which then served as catalysts in the conversion of N_2 into NH_3. This conversion could have produced nutrient molecules capable of supporting life. Under the conditions of the thermal vents, inorganic molecules could have given rise to organic monomers, which could combine to form polymers like amino acids which form peptides in the presence of iron and nickel sulfides. Once this chemical evolution was complete, the raw materials for biological evolution were readily available for the formation of membranes, proteins, and genetic materials that are the building blocks of the cell. 3. Cyanobacteria first carried on photosynthesis. The endosymbiotic theory explains the evolution of photosynthetic eukaryotes by taking up cyanobacteria, organisms believed to be responsible for introducing oxygen into the early atmosphere and thus allowing the evolution of animals. Without the introduction of oxygen to the atmosphere, the world as we know it would not exist.

CHAPTER 17

Check Your Progress

17.1 Yes, all protists are eukaryotes and have a nucleus. **17.2** Protists are a variable group and differ in size from microscopic to macroscopic; exhibit all possible life cycles, and ingest, absorb, or make their own food. **17.3** Contaminated water is a common source of Giardia infections. **17.4** A structural role. Silica is found in the tests of radiolarians. (It is also found in the cell walls of some plants and in the spicules of some sponges.) **17.5** Cilia give an organism the ability to move through the water and to direct water and food particles into a gullet for digestion. **17.6** A negative test for the spores merozoites. **17.7** As a result of the Irish potato famine, a large number of people emigrated from Ireland to the United States. **17.8** They are bound by protective cellulose plates that are impregnated by silicates. They also, typically, have two flagella. **17.9** A gelatinous product derived from some species of red algae. It is used as a solidifying agent for bacterial cultures. **17.10** Nucleic acid sequencing data.

Form Your Opinion

Page 337: 1. The theory of evolution has been supported by experimental evidence (see page 254) and by observation of fossil record, comparative anatomy, development, and chemistry of organisms. There are those who might point to gaps in the fossil record to cast doubt about the theory but the fossils record is becoming more complete as time passes. Science always seeks to broaden the scope of the theory of evolution. 2. The most reliable method for determining evolutionary lineages is a combination of both types of data. Using similarities and differences alone will not suffice because evolution is a variable process that can proceed "backwards" at times, reverting organisms back to their former state under some conditions. To bolster the data taken from simply comparing protist groups structurally, we can use genetic comparison as well. The combination of

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both types of data creates a more reliable case for evolutionary lineages than either type of data alone. 3. In order to avoid mistaken conclusions based on observational data, scientists should record results precisely and avoid bias as much as possible. They should check their conclusions with other scientists and observations should be conducted repeatedly to confirm findings.

Testing Yourself

1. d; 2. c; 3. a; 4. e; 5. Mitochondria were at one time free-living heterotrophic bacteria. 6. c; 7. b; 8. b; 9. c; 10. Flagella; trypanosomes cause disease, euglenoids contain chloroplasts. Pseudopods; amoeboids sometimes cause disease, foraminiferans and radiolarians form tests. Cilia; ciliates are complex and have trichocysts and undergo conjugation. None; apicomplexans cause diseases. 11. b; 12. c; 13. b; 14. b; 15. d; 16. b; ; 17. a; 18. b; 19. a; 20. b, c; 21. a, d; 22. b; 23. b; 24. b; 25. a; 26. b; 27. c; 28. d; 29. c; 30. a; 31. e; 32. Diatoms have a two valve shell of silica and become diatomaceous earth. Dinoflagellates have two flagella and cellulose plates and are responsible for "red tides." Red algae are variously structured seaweeds and are sources of agar and carrageean. Brown algae are seaweeds harvested for food and are a source of alginate (algin). 33. Brown algae, diatoms, and water molds are traditionally separate groups based on mode of nutrition and/or structure, but they are grouped together in the Stramenopila. This means that their DNA shows they are closely related.

Thinking Scientifically

1. If single cells do not separate, and if each cell divides in a way that allows the cells to join end on end, the end result could be a filament. 2. Merozoites enter red blood cells, and if you knew by what process they enter red blood cells, you might be able to develop a way to stop them from doing so.

Put the Pieces Together

Page 349: 1. Studying the first eukaryotes, the protists, with regard to their diversity of nutrition, reproduction, movement, and organization contributes to the study of biology in many ways. Protists can be used as models in the study of photosynthesis, examined for the role they play in the food chain, and studied for their medical impacts including malaria, dysentery, giardiasis, and Chagas disease. Through understanding the disease-causing ability of some protists, the large role others play in the food chain, or even the discrepancy in size between single-celled and multicellular protists, we gain an understanding of the diversity of life on our planet. 2. An evolutionary approach to relating the protists is a good one because it explores molecular data that can be analyzed more objectively than observational data. By analyzing the genome of protists and comparing it to that of other organisms, we can determine the relationship between the first eukaryotes and organisms like plants and animals. 3. The term kingdom Protista is longer used because of molecular evidence and suggestions that many more kingdoms exist within the diverse group of protists and that protists are not closely related to one another. Some protists are more closely related to plants or animals than to each other. To place them into a kingdom together, then, is inaccurate. The term protist remains because it refers to an organism that is not a plant, animal, or fungi.

CHAPTER 18

Check Your Progress

18.1 Cellulose cell walls, apical cells, plasmodesmata, and alternation of generations that includes protection of the zygote. **18.2** As in all plants the gametophyte produces gametes. **18.3** The sporophyte has vascular tissue and is protected from drying out by a cuticle interrupted by stomata. **18.4** Advantages:
The sporophyte embryo is protected from drying out, and the sporophyte produces windblown spores that are resistant to drying out. Disadvantage: The sperm are flagellated and need an outside source of moisture in order to swim to the egg. **18.5** The sporophyte is dominant and lycophytes have vascular tissue. **18.6** The independent gametophyte generation lacks vascular tissue, and it produces flagellated sperm. **18.7** (1) Water is not required for fertilization because pollen grains (male gametophytes) are windblown, and (2) ovules protect female gametophytes and become seeds that disperse the sporophyte, the generation that has vascular tissue. **18.8** Yes, insects do pollinate carnivorous plants, and seeds are produced and enclosed by fruit. The fruit is a dry capsule that contains seeds. **18.9** Fungi have the haploid life cycle in which only the zygote is diploid and the zygote undergoes meiosis to produce haploid spores. Plants have the alternation of generation life cycle in where are are two generations: the sporophyte produces spores by meiosis and the gametophyte produces gametes by mitosis. **18.10** Both are a mutualistic relationship between a fungus and a photosynthesizer and in both the fungus acquires food. **18.11** zyygospore fungi, black bread mold; sac fungi, truffles;club fungi, mushrooms.

Form Your Opinion

Page 364: 1. The plants present in an ancient swamp forest are the evolutionary predecessors of today's plants as well as the source of much of the energy that human beings use in the form of coal. Because we depend on plants for oxygen, food, and the energy produced by decomposed plants from millions of years ago, we are dependent on the plants that gave rise to present day plants. 2. Because the great swamp forest existed in what is now northern Europe, the Ukraine and the Appalachian mountains of the United States, I would predict that they occurred when the continents drifted and coalesced near the equator. Because the forest spanned what are now separate continents, they must have been present at a point when theses continents came together and these regions were near one another in a warm and humid environment not found in all of these locations today. The equator was the perfect setting for the tall seedless vascular plants to thrive before falling into the rising swamp waters.
Page 369: 1. Because it is possible that an infection could wipe out any or all of these three flowering grains, it is unfortunate that humans are so dependent upon only wheat, corn, and rice. To get people to eat more varied grains there would have to be an effort made to market alternative options at affordable prices. 2. In addition to the food they provide us, we are also dependent on plants because they are a source of oxygen, provide us with building materials, medicine, and fuel. We rely on plants for many things and thus could not live without them.
Page 374: 1. Decomposition, nutrient cycling, fermentation (yeast), food (mushrooms), antibiotic production, pest control. 2. No. Many organisms, including fungi and bacteria can be considered "bad" or "good" depending on the specific organism in question. While some fungi cause disease that can harm humans, others are a source of food, nutrient cycling, antibiotics, or pest control. For instance, fungi used for pest control also cause disease, but they do so in pests that might harm crops that humans use as food sources. Thus, all disease causing fungi are not "bad" since some are used to human advantage. 3. Plants can make their own food and need not live off of another organism for nourishment. A parasite like the fungus that causes athlete's foot can be likened to a predator, such as a lion, because they are heterotrophic and must find and consume food. Predators cannot make their own food either, and must hunt for and consume food.

Testing Yourself

1. a; 2. a; 3.a; 4. e; 5. Tall plants have better access to sunlight. 6. b; 7. a; 8. a; 9. e; 10. c; 11. b; 12. a. stigma; b. style; c. carpel; d. ovary; e. ovule; f. receptacle; g. sepal; h. petal; i. stamen; j. filament; k. anther. 13. a; 14. c; 15. e; 16. Pollen is less likely to be moved from the pollen cone to the seed cone of the same tree. 17. e; 18. e; 19. e; 20. e; 21. a; 22. e; 23. Mycorrhiza fungi are more likely to go along with the seedling in the native soil.

Thinking Scientifically

1. Only group (b) because mosses require a film of moisture in order for flagellated sperm to swim to an egg. 2. Because male moths attempt to mate with these flowers, they carry pollen only between flowers of this type.

Put the Pieces Together

Page 377: 1. It is not a good strategy to have a separate and water dependent gametophyte on land. It is a better strategy for the gametophyte to be protected by the sporophyrw which has vascular tissue. It is also better to have the sperm transported to the egg in a way that does not require external water. 2. DNA is a selfish molecule, copying itself without regard for any other processes taking place in a cell or an organism. The energy expended by plants for reproduction is merely a means to perpetuate the plant's DNA; reproduction, after all, is meant to pass on the genetic information of an organism to later generations so that the species may live on. 3. Yes answer: Reproduction of land plants and animals can be compared, because the adaptations of animals and plants are alike as they moved from aqueous environments to dry land. Both flowering plants and humans are able to protect all stages of their life cycle from drying our internal fertilization are all good adaptations required for reproduction on land. No answer: I do not approve of comparing reproduction in plants to reproduction in humans. Plants often require intervention from other organisms or abiotic factors like wind or water in order to reproduce successfully, while the reproductive process in humans involves direct contact between a male and female.

CHAPTER 19

Check Your Progress

19.1 Bats acquire nutrients from an outside source, ingest food and digest it internally, and have muscles and nerves. **19.2** Yes, because all animals can trace their ancestry to the same protistan ancestor.
19.3 Multicellular; tissue layers; bilateral symmetry, three tissue layers; body cavity; deuterostome development. **19.4** a. Sponges have the cellular level of organization, and bats have the organ-system level of organization; b. No, vampire bats simply have a liquid food, namely blood. **19.5** a. Microscopically, compare the development of cnidarians to that of bats; b. Cnidarians are predators that feed on live protists and small animals. Vampire bats are external parasites that feed on the blood of a host. **19.6** a. Yes; a longitudinal cut would divide the body in two equal halves; b. Bats are not hermaphrodites; the sexes are separate. **19.7** Vampire bats are external parasites; tapeworms and flukes are internal parasites that feed on nutrients meant for their host **19.8** Deuterostomes, as are all vertebrates. **19.9** Both bats and molluscs are

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multicellular, have three germ layers, have bilateral symmetry, and are coelomates with internal organs. However, molluscs are photostomes and bats are deuterostomes. **19.10** The sequential vertebrae of the spinal column. **19.11** This is not a feature that is used to distinguish to relatedness because it appears in both protostomes and deuterostomes. **19.12** a. Bats have jointed appendages, are segmented, and have a well-developed nervous system; b. Bats have an endoskeleton, not an exoskeleton; they all breathe by lungs; and they have reduced competition by diversifying. Some are fruit eaters, some are insect eaters, and some, such as vampire bats, are parasites. **19.13** Spiders, scorpions, millipedes, and centipedes. **19.14** Analogous, because insects and bats do not have a recent common ancestor. **19.15** a. Symmetry. Bats are bilaterally symmetrical and echinoderms are radially symmetrical; b. Both types of animals are deuterostomes. **19.16** As embryos. **19.17** Vertebrae, jaws, bony skeleton, lungs, limbs, amniotic egg, mammary glands. **19.18** Predaceous; actively ingesting chunks of food. **19.19** Yes; they have four limbs. **19.20** It provided a means for reptiles including birds, and mammals to reproduce on land in the absence of external water. **19.21** They are the only mammal that can fly (as opposed to glide) and the only mammal to hang by their feet alone.

Form Your Opinion

Page 389: 1. Before molecular analysis, biologists had to use observational comparison of organisms to decide who was related to whom. By comparing structure, nutrition and developmental information, among other characteristics, biologists did their best to determine relationships between organisms. 2. As seen in the example of the nemertine worm, anatomic data might lead scientists to believe that these organisms are closely related to flat worms; however, DNA data shows a closer relationship to the annelids and mollusks. Because of the complex evolutionary relationship between organisms, it is best if anatomic and DNA data support the same conclusion. 3. Biologists should certainly go into the field to study organisms. Observation of an organism within its natural environment is extremely important in understanding behavioral characteristics, reproduction and nutrition, for example. Therefore, the study of organisms should take place in the field as well as in the lab. **Page 406:** 1. Scientists think that it is unlikely that viruses will cross the species barrier; however, this has occurred in the past and may likely occur again due to the suppressed immune system of the human recipient along with the novelty of the animal disease(s) that may or may not be known human pathogens. Other unseen health consequences could result from the rapid and violent rejection of organs belonging to animal species that might lead to the death of the human recipient. There is also some concern over the genetic programming of humans versus animals: pigs, for example, age at a different rate than humans, presenting challenges in making any permanent transplants. 2. Yes answer: it is ethical to change the genetic makeup of vertebrates for use in drug or organ "manufacturing" so long as the animal is not harmed or killed in the process. No answer: It is not ethical to alter the vertebrate, use it as a factory or incubator, and then kill it in the process of harvesting the desired product. 3. It is possible that we are altering the relationship between humans and other vertebrates in a mutually detrimental way. The relationship between humans and the rest of the natural world should not be one of human expoitation and should avoid using vertebrates solely for our own purposes. If we slowly begin to alter every aspect of the planet for our own benefit, we may be forced to face consequences we never imagined possible.

Testing Yourself

1. d; 2. e; 3. e; 4. a; 5. b; 6. a; 7. e; 8. d; 9. d; 10. b; 11. a; 12. Flatworms are small, have a large absorptive surface, and are hermaphroditic. 13. e; 14. c; 15. e.; 16. a; 17. e; 18. b; 19. e; 20. Traditional fossils show how evolution occurred.

Thinking Scientifically

1. As per Section 19.1, study whole sponges and determine how they acquire food, whether they move, how they reproduce, and what developmental stages they have. Microscopically, determine the structure and function of their cells. 2. a. DNA/RNA sequencing; b. The data mentioned in Section 15.7: Fossil record and homologies in anatomy and development.

Put the Pieces Together

Page 409: 1. Ancestral protist, multicellularity, tissue layers, bilateral symmetry and 3 tissue layers and body cavity, deuterstome development, anestral chordates, vertebrae, jaws, bony skeleton, lungs, limbs, amniotic egg, mammary glands, mammals, humans (16 steps). 2. The advantages of the parasitic way of life include the reliance of a parasite on its host for food, shelter, and a place to disperse offspring with little to no energy expelnded by the parasite. Parasites, specialized for their way of life, can also reproduce at higher rates (more quickly and in greater numbers) than their host. The disadvantages of the parasitic way of life include dealing with any harm done to the host from the parasite leeching nutrients and invading the host organism. Parasites reduce the "fitness" of their host organism while increasing their "fitness" via exploitation of the host. 3. The relationship or sharing of a common descent, between humans and echinoderms can teach us that over time, changes in organisms including specialization, adaptation, and mutation create new organisms that may appear to have little in common though they originate from some common place in evolutionary history.

CHAPTER 20

Check Your Progress

20.1 Yes, because Ardi was a primate. **20.2** Mammalian ancestor to a common ancestor with prosimians; anthropoids, hominoids, and finally hominins in that order. **20.3** Ardi's features, including bipedalism, means that she is a hominin, even though her brain is small. **20.4** Southern African specimens were bipedal, but the arms were longer than the legs. Lucy, an East African species, was bipedal, and the arms were shorter than the legs. **20.5** This migration accounts for how the first Homo species arrived in Asia and Europe out of Africa. **20.6** An incomplete fossil record and the sudden appearance of Cro Magnon in Africa. **20.7** Their tool-making ability and other cultural attributes such as their artisitc talents. **20.8** a. People from any two ethnic groups produce fertile offspring. b. within ethnic groups.

Form Your Opinion

Page 420: 1. Culture is evident in almost all aspects of my daily life. Culture exists in traditions of cooking, eating, making a home, and using tools for cleaning, cooking, hanging a picture, creating written documents or drawing. 2. Aspects of my life that are influenced solely by biological inheritance have nothing to do with culture. For instance, I breathe, I eat, and I sleep because of the biology of being human. 3. Though our sources of food may be different than the hunter-gatherers, we still function in a similar manner, bringing nourishment back to a central location from a grocery store, farm, restaurant, etc. Also, it is still more customary for women to stay home to take care of the young and for men to go out and be aggressive in order to maintain the home base.
Page 423: 1. Many U.S. citizens can trace their ancestry to forbearers in the various other continents. This means they are descended from immigrants. This does not involve a migration pattern. 2. Yes, as humans migrated from continent to continent, genetic drift (founder effect) would have occurred and may have contributed to the similarity between members of a common ethnicity, but natural selection would have also occurred to favor advantageous phenotypes for the new environment. For instance, close to the equator and exposed to hot sun, darker pigments in the skin would have been beneficial and thus evolutionarily favorable. 3. I think that migration patterns show that all humans are related to one another. Studies that examine mtDNA show relatedness of populations on separate continents. The founder effect helps explain how differences in appearance might result from decreased genetic variation in a region inhabited by a small population. Natural selection helps to explain evolution of groups with different skin color, hair color or texture, and eye color.

Testing Yourself

1.a; 2. c; 3. common ancestor for prosimians, anthropoids, hominoids, hominins; 4. e; 5. Ardi evolved before Lucy and yet it has fewer chimp-like features than Lucy has; 6. d; 7. b; 8. b; 9. b; 10. d; 11. e; 12. b; 13. d; 14. e; 15 b; 16. Darwinian evolution is dependent on genetic differences, and biocultural evolution is dependent on advances that cannot be inherited. The ability to learn is inherited and learning is necessary to biocultural evolution. 17. c; 18. a; 19. c; 20. d; 21. d; 22. a. modern humans; b. archaic humans; c. Homo erectus; d. Homo erectus; e. Homo ergaster. 23. d; 24. There is more variation within ethnic groups. This tells us that all humans are one species.

Thinking Scientifically

1. The benefits of bipedalism must have outweighed the cost or else bipedalism wouldn't have evolved. 2. Sequence the Neandertal genome using DNA from Neandertal bones, and compare the sequence to the human genome of today. Look for sequences present in both genomes.

Put the Pieces Together

Page 427: 1. See page 382 figure 19.3A, and page 414 figure 20.2A. 2. I would suggest that biocultural evolution, "in which natural selection is influenced by cultural achievements rather than by anatomic phenotype," is more influential today than human biological evolution because of modern inventions like technology and medicine. Humans now have the ability to adapt to the environment through man-made methods including treating illness, and moving from one climate to another. Populations in regions without technology to keep water clean and treat illness are less successful than groups with clean water and medical care. 3. Through education we can explain the necessity of preserving habitats of organisms other than ourselves, and explain how biodiversity is necessary to the preservation of our planet and all its inhabitants including humans. Education could be used to demonstrate what happens when small or large changes are made to an ecosystem.

CHAPTER 21

Check Your Progress

21.1 When water is plentiful, leaves grow larger, maximizing solar absorption. When water is not available, narrow leaves help conserve water.

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21.2 Eudicot. **21.3** Collenchyma cells have areas of thicker primary cell walls, without having an entirely rigid secondary cell wall. **21.4** Xylem is located in the vascular cylinder of a root, the vascular bundles of a stem, and in the leaf veins of a leaf. **21.5** Shoot apical meristem produces more stem (including vascular bundles), axillary buds, leaves, and sometimes flowers. **21.6** It would signify a consistent amount of rainfall rather than a wet followed by a dry spell. **21.7** Epidermis protects, allows gas exchange, and regulates water loss. Closely packed epidermal cells covered by a waxy cuticle prevent water loss; however the stomata particularly on the lower surface allow gas exchange.The stomata close when water is scarce. Trichomes particularly on the upper suface help protect a plant from parasites. **21.8** Fungus roots help supply a plant with the water needed for photosynthesis; defense mechanisms prevent hungry insects from eating leaves; the organization of a plant is geared to carrying on photosynthesis.

Form Your Opinion

Page 435: 1. No answer: I do not find the consumption of an embryo, in the form of a grain, disturbing. Eating any plant is eating a living organism, and eating a steak, or chicken, or pork, is eating what used to be a living organism. Because nearly everything I consume used to be alive, eating grains, the embryos of plants, does not disturb me. Yes answer: I find it disturbing because of the word “embryo” and my tendency to equate that word with something immature that needs my help to become mature. 2. No answer: I would not mind eating only grains so that more people could be fed. Since grains provide more energy and cattle are polluting the environment, I would be happy to eat grains and not cattle. Grain can continue to be planted and harvested while cattle must be taken care of until old enough to be used as food. Yes answer: I would mind eating only grains so that more people could be fed. I like eating beef and want to continue to do so. People have been consuming cattle and other animals for some time and need to consider that our rapidly growing population needs all sorts of foods. **Page 443:** 1. Trees take in carbon dioxide, the byproduct of breathing in humans and animals, give off oxygen needed by most forms of life. Autotrophic plants produce sugar, the ultimate source of energy for animals and humans. Trees also create habitats above the ground for birds and many other animals. Because trees put oxygen into the atmosphere while removing carbon dioxide, provide energy for animals and humans in the form of sugar produced through photosynthesis, and create above ground habitats, they have and will continue to play a necessary role in the life of humans.

Testing Yourself

1. c; 2. c; 3. b; 4. c; 5. a; 6. Terminal bud is at the shoot tip and produces cells that add to the length of the stem and become new leaves and new axillary buds. Axillary bud activity produces new branches (and flowers). 7. A cereal grain is a dry fruit that contains a seed. 8. b; 9. c; 10. c; 11. b; 12. a; 13. d; 14. e; 15. c; 16. d; 17. a; 18. d; 19. b; 20. b; 21. b; 22. They all consists of parenchyma cells that fill the interior of an organ. 23. e; 24. c; 25. b; 26. b; 27. e; 28. c; 29. b; 30. Apical meristem (shoot tip and root tip meristem) is responsible for primary growth and the result is increase in the length of stem and root. Vascular cambium is responsible for secondary growth and the result is increase in girth. Girth increases because secondary xylem builds up as annual rings (wood). 31. c; 32. a. Broader expanse to collect sunlight; b. Prevents loss of water; c. Collects sunlight; d. Allows gas exchange; e. Allows carbon dioxide to enter and water to exit. 33. Photosynthesis allows a plant to produce the building blocks and ATP it needs to maintain metabolism and its structure. 34. e; 35. d; 36. b; 37. a; 38. c; 39. e

Thinking Scientifically

1. Confirm that plamodesmata do run between companion cells and sieve-tube members. Same as Palade, use labeled amino acids to show that proteins pass by way of plasmodesmata from companion cells to sieve-tube members. 2. Zone of cell division slides should show small cells dividing; zone of elongation slides should show cells that are longer than the previous zone—no cell division is occurring; zone of maturation should show mature tissues and epidermal cells with root hairs.

Put the Pieces Together

Page 449: 1. The presence of an epidermis and cuticle, stomata that open and close based upon the surrounding conditions, a root system, and a stem to carry water from the roots to leaves and flowers is evidence enough to convince me that the vegetative organs of plants have adapted to living on land. 2. A bush has more stems leading to its increased number of leaves, providing more vascular tissue for them. 3. Rhizomes provide an efficient way for plants to asexually multiply because each shoot represents an offspring of the parent plant.

CHAPTER 22

Check Your Progress

22.1 We will see that transport of sugar requires a functional plasma membrane. **22.2** Transpiration provides a means of transport for water and minerals and helps maintain internal leaf temperatures by providing evaporative cooling. **22.3** Cellular respiration, which requires oxygen, takes place in plant cells, even in the dark. **22.4** The roots are the source, and the flowers are the sink. **22.5** a. Nitrogen and sulfur are needed to form protein, and all plant roots take up nitrate (NO_3^-) and sulfate (SO_4^{2-}) from the soil; b. Nitrogen and phosphate (HPO_4^{2-}) are needed to make nucleic acids, and plant roots also take up phosphate from the soil. **22.6** The nonpolar tails of phospholipid molecules make the center of the plasma membrane nonpolar. **22.7** Plants develop root nodules when the amount of nitrate in the soil is not sufficient to support growth.

Form Your Opinion

Page 453: 1. Because of their remarkably long lives and great size, I would expect that redwoods are good competitors. Their shallow roots, capture water as it seeps into the ground from rainfall. Their thick fire-resistant bark allows them to survive a fire when other plants would burn. 2. Plant native grasses, trees, and shrubs along ditches or other unusable parts of land to prevent runoff and erosion, and promote insects that are natural pollinators and predators. Use pesticides sparingly and with deliberate attempts to avoid spraying during risky times for local insects, fish, or other wildlife. Plant various crops including those useful for ground cover. 3. I am certainly willing to eat new grains in order for farmers to increase biodiversity. Maintaining biodiversity is good for the planet as a whole. If simple changes like eating habits can assist in keeping our planet a suitable home for many organisms, I'd be happy to do so. **Page 457:** 1. Plants are a source of food, make oxygen, take in carbon dioxide, provide shelter, serve as building materials, clean up nitrate pollution, grow materials used for clothing like cotton, produce or aid in production of medicines, and serve to preserve soil. 2. Find some way to prevent pets and other animals from having access to these plants; actully it would be best to stop polluting the biosphere; then, we would not have to use plants to rid an area of the pollutant. 3. Society has to be willing to pay the cost of cleaning up the environment or else people and other living things may perish. I personally would be willing to pay a price for the rare and beneficial service of a plant that could filter pollutants from soil or water to benefit the environment.

Testing Yourself

1. a; 2. Leaves must receive water for photosynthesis, and they produce sugar as a result of photosynthesis. 3. c; 4. d; 5 Atmospheric pressure cannot account for the ability of water to rise above 76 cm in a plant. However, transpiration does allow water to rise above 76 cm. 6. c; 7. d; 8. e; 9. c; 10. d; 11. b; 12. a; 13. e; 14. Water enters the first bulb by osmosis and this creates a pressure flow that moves the solute to the second bulb and beyond. 15. c; 16. d; 17. b; 18. d; 19. a; 20. b; 21. e; 22. c; 23. e; 24. c

Thinking Scientifically

1. Due to diversity, some species may not be susceptible to the assault. Also, the susceptible plants may be protected by the unsusceptible. For example, insects may not find all the susceptible plants, or most of the available water will go to those plants that need it. 2. Divide a large number of identical plants into control and experimental groups. Both groups are to receive the same treatment, including all necessary nutrients, but the experimental group will not be given any calcium. It is expected that only the experimental group will suffer any ill effects. If only the control or if both groups do poorly, some unknown variable is affecting the results.

Put the Pieces Together

Page 467: 1. Plants require inorganic nutrients from the environment in order to build organic molecules necessary for life. Carbohydrates are used to form their cell walls and to respire. Cellular respiration provides the plant's cells with energy. 2. Plant cells absorb water and minerals through their root systems. The minerals are taken into the cells in their charged or ionic forms. The movement of ions across the plant cell plasma membrane requires active transport but it allows plants to concentrate minerals in their cells. When animals consume plants, they take in these concentrated minerals. 3. It is beneficial to have xylem and phloem in the same vascular bundle because in this way they are supported by the same sclerenchyma cells (in stems) and are surrounded by the same bundle shealth cells (in leaves).

CHAPTER 23

Check Your Progress

23.1 Different second messengers can bring about various cellular activities in the same or different types of plant cells. **23.2** Yes, because if the hormone remained, it would continue to trigger a response long after the response was no longer needed. For example, it would bring about bending after the light source was no longer present. **23.3** The plant in (a) most likely doesn't produce gibberellin, and the receptor in (b) is more likely defective. **23.4** You could apply cytokinins to increase the number of cells and gibberellins to increase the size of the cells. **23.5** a. Abscisic acid maintains dormancy and closes stomata; b. Gibberellins have the opposite effect. **23.6** To be an effective hormone, a molecule needs only to combine with its receptor. **23.7** It is adaptive for roots to grow toward water because it enhances their ability to extract water and dissolve minerals from the soil for

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plant tissues. **23.8** Rotation will prevent the statoliths from settling and triggering differential growth. Therefore, neither the root nor the shoot is expected to curve up or down. **23.9** These animals are nocturnal, so it would be a waste of energy to produce scent during the day. **23.10** Red light converts P_r to P_{fr}; P_{fr} binds to a transcription factor; and the complex moves to the nucleus, where it binds to DNA so that genes are turned on or off. **23.11** The plant is responding to a short night, not to the length of the day. **23.12** Most likely not. Many activities of organisms are simply adaptations to the environment that occur automatically.

Form Your Opinion

Page 484: 1. Humans rely upon plants as a source of food and oxygen as well as filters to remove carbon dioxide from the air. Plants provide human beings with the raw materials for shelter, a means to clean up nitrate pollution, grow materials used for clothing like cotton, produce or aid in production of medicines, and tools in soil preservation. 2. Some secondary metabolites produced by plants for defense, can inhibit cellular respiration and block DNA or RNA synthesis, making them useful in the fight against cancer.

Testing Yourself

1. c; 2. a; 3. d; 4. a; 5. c; 6. c; 7. d; 8. e; 9. d; 10. d; 11. b; 12. e; 13. a; 14. c; 15. Place the banana in a closed container with a ripened fruit. 16. d; 17. c; 18. d; 19. e; 20. a. active form of phytochrome, b. biological response, c. far-red light; d. red light 21. c; 22. b; 23. e; 24. a; 25. e; 26. b; 27. d

Thinking Scientifically

1. Use a plant that tracks the sun as your experimental material. Make tissue slides to confirm the presence of a pulvinus, as in Figure 23.9. Apply ABA to live pulvinus tissue under the microscope to test for the results described in Figure 23.9. 2. Shine a light underneath a plant growing on its side (see Fig. 23.8A, upper left). If the stem now curves down, the phototropic response is greater than the gravitropic response and your hypothesis is not supported.

Put the Pieces Together

Page 487: 1. Population: Members of a plant population that opened and closed their stomata morning and night had an advantage over plants that did not do this. Organism: Sunlight acts as a stimulus that causes stomata to open during the day; the absence of sunlight causes stomata to close. Cellular: When K^+ enters guard cells, water follows, and stomata open. When K^+ exits guard cells water follows, and stomata close. Abscisic acid brings about closure of stomata in a plant that is water stressed. 2. (1) Reception of the stimulus: red light, in day light, activates phytochrome. (2) Transduction of the stimulus: activated phytochrome moves into the nucleus, binding specific proteins, and activating specific genes. (3) Response to the stimulus: Flowering occurs. 3. Auxins: suppress lateral growth; Gibberellins: result in stem (internode) growth; Cytokinins: stimulate cell division; Abscisic acid: promotes dormancy; Ethylene: causes abscission of leaves; therefore reduces growth.

CHAPTER 24

Check Your Progress

24.1 Pollen grains (the male gametophytes) are visible when the anther releases them. To find the female gametophyte, you would have to microscopically examine the contents of an ovule just before fertilization takes place. **24.2** One sperm unites with the egg to form an embryo and the other combines with two polar nuclei forming a triploid (3n) endosperm cell. **24.3** The ovule is a sporophyte structure produced by the female parent. Therefore, the ovule wall (becomes seed coat) is 2n. The embryo inside the ovule is the product of fertilization and is, therefore, 2n. **24.4** Showy, colorful flowers attract pollinators; colorful fruit that is a good food source attracts animals which transport seeds away from the parent plant. **24.5** The sheaths protect the shoot and root apical meristems from damage as they push through the soil. **24.6** Advantages to asexual reproduction include: (1) By passes the requirements for sexual reproduction: gamete production, pollination, seed production and dispersal. (2) if the parent is ideally suited for the environment of a given area, the offspring will be as well. **24.7** a. Either somatic embryogenesis or meristem tissue culture. b. Cell suspension culture would allow you to collect chemicals produced by a plant.

Form Your Opinion

Page 492: 1. A series of mutations are needed for a non-seed life cycle to evolved into the seed life cycle: (1) Sporophyte produces heterospores that develop into microscopic male and female gametophytes. (2) Female gametophyte is retained by sporophyte (3) Male gametophyte becomes pollen grain. (4) Following fertilization, the embryo sac becomes a seed. (5) Seed contains sporophyte embryo, food, and seed coat. 2. Humans are reproductively adapted to protect all stages of reproduction in a dry environment, much like seed plants. Human gametes are housed in the ovaries and testes and fertilization occurs internally. A fertilized egg implants in the uterus and is protected and nourished here until it is mature enough for birth and development outside the body of the mother. 3. Flowers and seed cones both bear ovules that develop into seeds. Ovules first contain a megaspore and then a female gametophyte. Following fertilization, both flowers and seed cones produce seeds. Only the seeds of angiosperm are protected by fruit. A seed cone plays no part in the development of pollen as most flowers do.
Page 493: 1. Observe several different flower types and and see if they are visited by only one type or several types of pollinators. 2. The efficiency of wind pollination is most likely low since gymnosperms produce a large amount of pollen.

Testing Yourself

1. b; 2. b; 3. a; 4. e; 5. a. anther; b. filament; c. stamen; d. stigma; e. style; f. ovary; g. ovule; h. carpel. 6. d; 7. c; 8. b; 9. a; 10. e; 11. c; 12. d; 13. b; 14. d; 15. a; 16. A wind pollinated plant produces more pollen because the method of pollen transfer is less efficient. 17. b; 18. a; 19. e; 20. c; 21. b; 22. d; 23. e; 24. The need for a period of cold weather helps ensure that the seeds germinate when the weather will be favorable to continued growth. 25. c; 26. e; 27. a; 28. When the environment is not changing or when male and female plants are not in close proximity.

Thinking Scientifically

1. Study (a) the anatomy of the wasp and flower, trying to determine if the mouth parts of the wasp are suitable for collecting nectar from this flower; (b) Study the appearance of the flower in sunlight/ultraviolet light to determine suitability to the vision of the wasp; and (c) Study the behavior of the wasp to see if it is compatible to that of the flower (i.e. flower is open when wasp is active). 2. Protoplasts can be made from leaf cells and then cultured to grow entire plants. These plants are expected to produce seeds that you can use to propagate the plant.

Put the Pieces Together

Page 503: 1. Within the seeds of angiosperms, the endosperm provides nutrients. 2. (1) Flowers have benefited from the use of animals in pollination. This has made flowers successful reproducers on land, producing more seeds. Animals have benefited from this relationship because they received food in the form of sugary nectar from plants. (2) Fruit produced by plants, eaten by animals, has aided flowering plants in seed dispersal. In this relationship, the animal also benefits from the nutrition received from the fruit of the flowering plant. 3. Flowering plants (but not ferns) produce (1) two types of spores, microspores and megaspores and (2) two types of gametophytes: male and female gametophytes.

CHAPTER 25

Check Your Progress

25.1 Fur traps heat and does not release it. **25.2** Evaporative cooling; water in sweat absorbs heat energy to become vapor. **25.3** Polar bear; adipose tissue helps keep the polar bear warm and is a source of nutrients when food is scarce. **25.4** Blood vessels taking blood to the surface constrict in order to reduce heat loss through the skin. **25.5** Dendrites are numerous and gather input from other neurons; the long axon is appropriate for conveying nervous impulses some distance. **25.6** The thick skin of a gila monster helps prevent the loss of water, rather than helping to regulate body temperature. However, a thick skin would help lessen the gain of heat in a warm environment. **25.7** Sensory receptors respond to a change in body temperature and communicate this information to the brain, which then commands motor activity to perform the behavior that will warm or cool the body, as needed. **25.8** Enzymatic reactions are necessary to the life of a cell, and enzymes function best at a moderate body temperature. **25.9** An early morning cool body temperature causes the lizard to move into the sun, where it stays until the body temperature is too hot, causing the lizard to seek shade. Thus, its behavior alternates back and forth.

Form Your Opinion

Page 514: 1. Yes, I am willing to contribute to stem cell research if my involvement could give someone the ability to regain function in their limbs, to walk again, for example. We all engage in voluntary activities that can cause injury. No, I am not willing to contribute to stem cell research because stem cell research is a controversial field of science and medicine. 2. I believe it is unfair to limit new and innovative therapies to the well-known or wealthy and it should be available to any one. 3. Yes, celebrities, like Christopher Reeve, should be used to increase interest in nervous system regeneration research. Putting a recognizable name and face on science and its potential advancements can be advantageous to everyone involved. No, celebrities should not be used to endorse or publicize causes like nervous system regeneration research. By involving celebrities the treatment might become political.
Page 520: 1. For instance, the brain must communicate with the heart and lungs in order for heart to pump blood and the lungs exchange gases in a coordinated manner. 2. A terrestrial animal but not an aquatic one has the added burden of water conservation. 3. Our skin prevents water loss, our large intestine absorbs water and our kidneys can excrete a hypertonic urine if we do not drink enough that day. Blood volume is maintained so that tissue fluid can provide an aquatic environment for our cells.

Testing Yourself

1. c; 2. a; 3. a; 4. d; 5. e; 6. d; 7. b; 8. d; 9. The dendrites offer wide surface area for the reception of stimuli and the long axon is suitable for the transmission of stimuli. 10. a, c, g; 11. b, d, e;

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12. b, c, f; 13. a; 14. b; 15. c; 16. Epithelial cells are exposed to mutagens (agents that cause mutations) in the environment. Also, high rate of cell division means that spontaneous mutations may occur that lead to cancer. 17. e; 18. c; 19. The epidermis is composed of stratified epithelium, which provides an impenetrable barrier to invasion by microorganisms. 20. a; 21. b; 22. e; 23. d; 24. e; 25. c; 26. a; 27. a; 28. e; 29. Shivering is due to muscle contraction which gives off heat. 30. You would expect the cardiovascular system to have a pump (the heart) to move a liquid (blood) through tubular vessels.

Thinking Scientifically

1. Examine the tissue visually, trying to determine the particular organ before preparing microscope slides so that you can compare the slides you have made to known tissue slides. 2. Test two groups: (1) People who visit tanning salons, say two or more times a week. (2) People who never vistit tanning salons. Find out how many people in each group have been treated for skin cancer. Compare the percentages and determine if the difference is significant.

Put the Pieces Together

Page 523: 1. When the human body is cold, signals are sent to the bones and muscles to initiate movement which results in shivering. Shivering increases blood flow and body temperature. As soon as possible humans move to a more suitable environment to achieve homeostasis. 2. People who travel to the South Pole wear special clothing and take shelters that help maintain body temperature and prevent water loss. People who walk in space have a space suit that maintains their normal environment and provides them with the support systems they need (e.g., availability of oxygen). 3. No, because blood and tissue fluid are external to cells. Yes, because blood and tissue fluid are inside the body.

CHAPTER 26

Check Your Progress

26.1 a. neurons and neuroglia; interneurons; b. sensory neurons and motor neurons **26.2** a. It distributes the ions appropriately because Na^+ is pumped to the outside of an axon, and K^+ is pumped to the inside. b. Na^+ moves to the inside of the axon and then K^+ moves to the outside of an axon. **26.3** Saltatory conduction. **26.4** Neurotransmitters that cross the synaptic cleft. **26.5** Inhibition of AChE would cause ACh to remain in a synapse. A drug that interferes with neurotransmitter breakdown enhances its action. **26.6** The neurons of the brain receive signals via the spinal cord from all the rest of the nervous system. **26.7** A chimpanzee's brain would be very similar to ours but smaller. **26.8** When sleeping occurs, the sleep center is active and the RAS is inactive. **26.9** The amygdala adds emotional overtones to experiences. **26.10** Without the PNS, the CNS would neither receive stimuli nor be able to direct a response to the stimuli. **26.11** a. spinal cord; b. brain **26.12** Sensing danger because of input from sensory receptors, the brain sends nerve impulses via the spinal cord to the skeletal musces and to nerve fibers of the sympathetic division of the autonomic system. The sympathetic division shuts down unnecessary functions and enhances those that can help manage the crises.

Form Your Opinion

Page 533: 1. Both animals have a central and peripheral nervous system. Planarians have a ladder-like nervous system with two nerve chords connected to the cerebral ganglia and extend to the posterior end of the body. Transverse nerves connect the nerve chords and the ganglia to the eye spots. The human nervous system is composed of a brain, and spinal cord from which branches a network of nerves throughout the body. 2. The arthropod nerve cord is ventrally placed while the vertebrate nerve cord is dorsally placed. 3. No, the structure and function of the nervous system in all mammals is about the same.

Testing Yourself

1. d; 2. c; 3. b; 4. a; 5. b; 6. New characters often arise by modifications of previously evolved characters. 7. c; 8. b; 9. Myelination enables signals to travel quickly down an axon, which helps motor skills. 10. a; 11. c; 12. d; 13. e; 14. Learning requires the formation fo new associations and this is mirrored in the brain by the formation of new synapses. 15. a central canal; b. gray matter; c. white matter; d. interneuron; e. dorsal root ganglion; f. cell body of motor neuron; 16. a; 17. d; 18. d; 19. d; 20. They affect the limbic system and either promote or decrease the action of a particular neurotransmitter.

Thinking Scientifically

1. Administer a medication that interferes with the reception of norepinephrine at a synapse. The patient may not respond properly to a real danger. 2. Severed sensory neurons are still releasing neurotransmitters in the spinal cord, resulting in messages to the brain that are interpreted as pain in the limb.

Put the Pieces Together

Page 547: 1. The nervous system is composed of two parts, the brain and spinal cord (central nervous system) and the nerves and ganglia (peripheral nervous system). The central nervous system receives information from the body, integrates it , and sends instructions to the body's muscles and glands via the nerves of the peripheral nervous system. They respond. 2. Neurons are the functional units of both the CNS and the PNS; therefore, every thought, feeling, and emotion we have and action we take is dependent on the nerve impulse and transmission across a synapse. 3. The limbic system influences motor output by its communication with the forebrain.

CHAPTER 27

Check Your Progress

27.1 Eyes are sensitive to visible light rays and sometimes to ultraviolet rays, both of which are part of the electromagnetic spectrum. **27.2** Eyes receive stimuli and initiate nerve impulses; the optic nerve sends impulses to the brain; and the visual cortex of the brain interprets the stimuli, resulting in formation of an image. **27.3** a. Pheromones combine with a chemoreceptor that initiates a nerve impulse; b. Pheromones are signals sent by one member of a species to affect the behavior of another member. **27.4** No, photoreceptors contain pigments that absorb light. **27.5** The color we see is dependent upon which combination of cones is stimulated. **27.6** The compound eye has many independent visual units, but the retina of the camera-type eye is one large visual unit. **27.7** A lens can accommodate—change shape as needed. **27.8** a. Ganglion cell layer, bipolar cell layer, rod and cone cell layer; b. Rod and cone cell layer, bipolar cell layer, ganglion cell layer (whose axons form the optic nerve). **27.9** Maintain muscle tone and help maintain the body's balance and posture. **27.10** outer: gather sound waves; middle:amplify sound waves; inner: hearing **27.11** Bending of hair cells is a mechanical event. **27.12** a. When the head rotates cupulas are displaced and this causes stereocilia in the ampullae of the semicircular canals to bend. b. When the head bends, otoliths are displaced causing a membrane in the utricle and saccule to sag and stereocilia to bend.

Form Your Opinion

Page 555: 1. Damage to the retina will cause loss of vision; other damages may be repaired. For example, inflammation of the conjunctivae, may cause some blurring of vision but if treated , vision will improve. 2. Yes answer: My vision is important to me for my safety as well as enjoyment of the world around me. No answer: I would rather enjoy life as I like and be willing to take the consequences.
Page 556: 1. This is reasonable because of cultural influences that make a person seem disabled if they wear glasses or that make them they are "nerds". However, I think it is wise to disregard any stigmatism and do what is best for oneself. 2. Everyone should weigh the consequences of their actions and after being well informed, do what is best for them.
Page 561: 1. I would rather participate in rock concerts and exercise classes with the aid of earplugs to preserve my hearing. 2. We should not be annoyed because it could be too that they did protect their hearing and their hearing loss is due to no fault of their own.
Page 564: 1. It shows that evolution makes use of the structures available to it rather than inventing something new. 2. The inner ear of mammals evolved from our predecessors, water dwelling animals. As such, it would make evolutionary sense that the inner ear of mammals makes use of fluid pressure waves, as our aquatic ancestors would have. 3. Mammals evolved on land and use vision as well as sound to detect the presence of other organisms. Sound waves are amplified by the presence of three ossicles surrounded by air in the middle ear.

Testing Yourself

1. e; 2. c; 3. The brain requires input from sensory receptors in order to produce sensations about the world at large. 4. a; 5. See Fig. 27.6; 6. near object; 7. d; 8. c; 9. c; 10. c; 11. b; 12. e; 13. d; 14. c; 15. Both procedures can correct an inability to focus properly; The first with an artificial lens and the second by changing the shape of the cornea. 16. Rather than visual information, a blind person uses information from proprioceptors in joints and tendons and touch receptors for example in the buttocks to know they are sitting in a chair. 17. See Fig. 27.10; 18. a; 19. a; 20. c; 21. c; 22. c; 23. c; 24. b; 25. a; 26. b

Thinking Scientifically

1. One possible answer: The size of the auditory cortex is larger in those who have perfect pitch. Test the pitch ability of subjects, and then stimulate the brain directly to determine the size of the auditory cortex.
2. LASIK surgery only corrects the shape of the cornea in order to achieve 20/20 vision.

Put the Pieces Together

Page 567: 1. Human beings' keenest senses are probably hearing and vision, which would have been adaptive for a primate dwelling on land and seeking food and shelter and protection in trees.
2. Parents use touch, vision and sound to bond with their children. Birds use the same senses. 3. I would give up taste as a weight control mechanism.

CHAPTER 28

Check Your Progress

28.1 Exoskeletons and endoskeletons are likely to be a part of the fossil record because they do not decompose, as do the soft hydrostatic skeletons of animals. **28.2** The bones provide a frame for the body after death. Even disconnected bones can help a forensics expert determine what the person looked like. **28.3** skull: zygomatic and parietal bone; rib cage: sternum; vertebral column: sacrum.
28.4 Gender of the individual and the condition of

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the pubic symphysis, which gives an indication of age. **28.5** A long bone in the appendicular skeleton, such as the humerus or the femur, would be suitable for calculating height. **28.6** As we age, the joints deteriorate, so their condition can be used to roughly indicate age. **28.7** During shivering, the skeletal muscles contract quite rapidly, generating heat, which can help maintain normal body temperature. **28.8** More motor units are recruited to lift three books. **28.9** A myofibril is a long, cylindrical structure in a muscle cell. A sarcomere is a section of a myofibril. **28.10** The events shown in Figure 28.10B #1–3. **28.11** A neuromuscular junction occurs between an axon terminal and a muscle cell; a synapse occurs between an axon terminal of one neuron and either the dendrite or cell body of the next neuron. **28.12** The CP pathway uses creatine phosphate. **28.13** To a degree—for example, a weight lifter would have larger bones with larger protuberances. If the musculature could be observed, it would be well developed.

Form Your Opinion

Page 575: 1. A larger human brain and upright posture might be evolutionarily connected because as walking upright evolved, increased brain size was also needed to ensure the coordination and balance required for upright posture. 2. Arthritis, tendonitis, ligament tears and other injuries suggest that the knee is not fully adapted to bearing weight. Also, the knees are subject to injury when playing sports.
Page 578: 1. We should give people the benefit of the doubt because knowledge about osteoporosis is relatively new some people are more prone to the disease than others. 2. Screening for osteoporosis should be part of any type of physical exam.
3. Payment for health insurance should be on a sliding scale dependent on the health habits of the individual. Smoking can be detected by chronic bronchitis; lack of exercise can be detected by their musculature.
Page 581: 1. People say they are too busy, do not belong to a gym, and don't know how to work it into their daily lives. However, many alternative methods for exercising can be done even at home.
2. It is not helpful and it would be more accurate to say that results do not come without work.

Testing Yourself

1. a; 2. c; 3. e; 4. b; 5. c; 6. b; 7. c; 8. b; 9. f; 10. c; 11. e; 12. c; 13. d; 14. a; 15. c; 16. a; 17. e; 18. b; 19. Pelvic girdle is too small for a normal delivery. 20. a; 21. b; 22. c; 23. b; 24. d; 25. a; 26. e; 27. Unless they were attached, myosin couldn't cause the actin filaments to move thereby shortening sarcomeres. 28. b; 29. a; 30. a

Thinking Scientifically

1. Remove muscle tissue from a corpse in rigor mortis, slice it thin. While watching under the microscope, flood your slide with ATP and necessary ions to see if muscle relaxes and then contracts. 2. Acquire two test groups: aerobic instructors and confirmed couch potatoes. Oxygen tanks supply their only air, while they are running on a tread mill. Those who routinely exercise have more mitochondria than those who do not exercise, accounting for why the first group uses less oxygen and has less lactate (lactic acid) in their blood.

Put the Pieces Together

Page 587: 1. Animals are heterotrophs and have to seek their food. Nerves and muscles assist animals in pursuing their way of life such as being a predator or escaping predation. 2. To take an example, the pelvis and femur meet in a ball and socket, a synovial joint that allows for the rotational mobility of the hip, while the fibrous joints of the skull are immovable. These immovable joints have an important function since the bones of the skull must remain intact in order to protect the brain. There are three types of muscles: (1) Skeletal muscles are striated for strength and voluntary contraction when needed to move bones. (2) Cardiac muscle is striated for strength, but involuntary, ensuring that the heart continues to beat. (3) Smooth muscle is nonstriated and involuntary, ensuring that the muscles of the digestive tract always perform peristalsis. 3. Jointed appendages allow arthropods and vertebrates to perform flexible movements needed for walking, running, jumping on land.

CHAPTER 29

Check Your Progress

29.1 Open systems utilize hemolymph; run freely into a hemocoel; heart has ostia. Closed systems utilize blood; always contained in vessels; heart has no ostia. **29.2** The right side of the heart contains more O_2-poor blood and the left side of the heart contains more O_2-rich blood. **29.3** a. SA node activity is responsible for atrial systole; b. AV node activity is responsible for ventricular systole. **29.4** a. Blood pressure moves blood in arteries; b. Mechanical pressure exerted by skeletal muscle contraction helps move blood in veins. **29.5** No, try as you will in Figure 29.8. This ensures that all blood passes through the lungs. **29.6** No, it is highest close to the heart and falls off dramatically after moving through the capillaries. **29.7** Blood is composed of blood cells (plus platelets) in a liquid matrix called plasma. **29.8** Tissue fluid is derived from plasma at cardiovascular capillaries. Excess tissue fluid is absorbed by lymphatic vessels and becomes lymph. **29.9** The steps prevent clotting from occurring unnecessarily. **29.10** A type B recipient has anti-A antibodies in the plasma, and they will react with the donor's red blood cells, causing agglutination.

Form Your Opinion

Page 593: 1. Most likely reptiles (bird and crocodiles) and mammals express this gene because their heart has a septum, which completely separates the ventricles.
Page 596: 1. I believe that open heart surgery should be paid for by insurance, especially in cases where the need for the surgery is a genetic condition or birth defect. I believe the operation should be paid for by the patient based on ability to pay to help offset the cost of insurance premiums, especially in cases where cardiac health has suffered due to poor diet, lack of exercise, or drug abuse. 2. Ideally, people would follow the guidelines for staying fit and would not need to rely on the medical profession to make them healthy after they've abused their bodies.
Page 597: 1. Recommendations not to smoke or abuse drugs would be easier for me to follow than recommendations for diet and exercise. Food and laziness are easier for me to buy into than cigarettes and drugs. 2. I think education including the opportunity to see the effects of poor diet, lack of exercise and/or effects of drug use is the best method to make for making young people realize that they should take care of their bodies.
Page 601: 1. Because our culture emphasizes success, athletes are inclined to use performance-enhancing procedures or drugs in order to win competitions. Athletes found to be using illegal drugs and procedures should be banned from competition in their respective sport and any medical personnel or trainer that assists the athlete should be prosecuted and face loss of medical license, because the drugs and procedures can cause death.
Page 603: 1. I would be willing to let leaches feed on my blood for a few minutes if it would improve my chances of recovery from an injury, especially since this treatment is FDA approved. No, I would not be willing to let leaches feast on my blood because it would make me uncomfortable. 2. The idea that diseases could be transported throughout the body by the circulatory system might have given physicians the idea that by removing blood the illness might also be lessened.

Testing Yourself

1.d; 2. c; 3. b; 4. Efficient delivery of oxygen to the muscles allows birds and mammals to have an active lifestyle and generate heat to maintain a warm body temperature. 5. a; 6. See Fig. 29.2; 7. d; 8. c; 9. c; 10. b; 11. d; 12. c; 13. b; 14. a. blood pressure b. osmotic pressure c. blood pressure d. osmotic pressure; 15. a; 16. d; 17. e; 18. b; 19 Erthropoietin increases the number of red blood cells, and Rita's problem is lack of iron in her diet.

Thinking Scientifically

1. (1) By dissecting animals, you will see three different types of blood vessels; the valves in the heart directed toward the arteries and in the veins valves directed toward the heart. (2) A deep cut to a vertebrate limb draws bright, red arterial blood under pressure; pressing on a vein causes it to expand on the far side. This could only be if the blood circulates. 2. The amount of amino acids, sugar, and oxygen is higher in arterial blood and the amount of bicarbonate ion is higher in venous blood. Nutrients and oxygen leave a capillary and carbon dioxide enters a capillary midway along it's length. When carbon dioxide enters the capillary, the main portion becomes the bicarbonate ion.

Put the Pieces Together

Page 607: 1. Circulatory systems always have exchange surfaces with the external environment so they can keep the internal environment constant. For example, aquatic animals have gills and terrestrial animals have lungs where gas exchange occurs.They also exchange materials with the cells because their ultimate function is to serve the needs of cells. 2. When the blood is returning to the heart, it lacks the blood pressure provided by the pumping of the heart and venous blood may be traveling against gravity to move from the extremities back to the heart. 3. Blood pressure and therefore blood flow would be reduced due to the movement of water into tissue fluid.

CHAPTER 30

Check Your Progress

30.1 They return excess tissue fluid to cardiovascular veins. Without the return of this fluid, the tissues would become water-logged, blood pressure would drop dramatically, and blood circulation would falter. **30.2** The red bone marrow can produce thousands of T cells every day to stay ahead of those being killed by the virus. As long as the red bone marrow can produce more helper T cells than are being destroyed by an HIV infection, the person can fight off infections. **30.3** All three categories are helpful. The lining of the vagina is protective; interferons, macrophages, and natural killer cells should be helpful as well. **30.4** Macrophages and dendritic cells, because they activate T cells. **30.5** Yes, because it is specific to the virus and foreign to humans. **30.6** As long as active antibodies are present in the body, the person remains immun to a disease. **30.7** HIV attacks and lives inside helper T cells. Destruction of helper T cells occurs when the viruses bud from the cell. Therefore, as the infection progresses, fewer T cells are available to perform their usual functions, and the immune system fails. **30.8** No; each antibody is effective only against one specific antigen. **30.9** HIV destroys helper

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T cells, and the number of cytokine-secreting helper T cells declines. Eventually, the immune system is ineffective, and the person, if untreated, dies. **30.10** The compromised immune system would make rejection less of an issue, but the patient would be susceptible to all sorts of possible pathogen infections due to the surgery. **30.11** If the disease is untreated, the quality of life suffers. If the disease is treated with immunosuppressive drugs, patients may be more susceptible to pathogenic infections.

Form Your Opinion

Page 613: 1. Fever seems beneficial when it makes us slow down but harmful because it makes us realize we are sick. 2. Most people cannot resist treating a fever because a fever makes them feel uncomfortable and just doing away with the fever makes them feel better.
Page 620: 1. Cancer is caused by an agent that can affect our genes. Monoclonal antibodies do not activate transduction pathways nor activate genes. 2. Yes, the patient should have been asked for her consent and should have been compensated. Even now her heirs could be compensated.
Page 622: 1. Contact with an allergen over a period of time can lead to an allergic response. 2. The presence of IgG antibodies can prevent an allergic response. Good hygiene in developed countries has resulted in fewer types of antibodies in people's blood and tissues.

Testing Yourself

1.a; 2. b; 3. d; 4. b; 5. It collects excess tissue fluid at the blood capillaries and returns it to the subclavian veins of the cardiovascular system. 6. b; 7. e; 8. d; 9. a; 10. Fever creates an unfavorable environment for an invader and may stimulate the immune system. 11. See Fig. 30.7; 12. c; 13. d; 14. a; 15. a; 16. a; 17. b; 18. e; 19. e; 20. B and T cells are specific to the agent that has harmed the body. 21. c

Thinking Scientifically

1. Hypothesis: each type of antibody is coded for by a different sequence of exons from the same gene or genes. 2. Control group is vaccinated against a specific disease and then the pathogen is administered. They are expected to remain well. The test group is vaccinated against a specific disease and then is administered the drug plus the pathogen. If the drug suppresses antibody mediated defense, the test group will become ill. Repeat the procedure for other diseases.

Put the Pieces Together

Page 625: 1. An antibody-mediated response is needed to identify and destroy the virus once it is in the blood. If the viral DNA has integrated itself into the infected cell's genome, then cell-mediated immunity is also needed. During cell-mediated immunity, cytotoxic T cells destroy a cell infected with a virus. 2. The clonal selection process results in the production of a specific antibody. Therefore, the antibodies produced after exposure to HIV would not be present if exposure had not taken place. 3. Following a viral infection a body cell might mistakenly display a viral antigen. Natural killer cells (innate immunity) attack these body cells. Also, an APC cell detects the antigen and presents it to a T cell. (adaptive immunity). The T cell attacks the body cell even though it is no longer infected.

CHAPTER 31

Check Your Progress

31.1 Carnivores are predators that attack and kill other animals. Digestion (both mechanical and chemical) of meat is more easily accomplished than the digestion of carbohydrates. **31.2** a. Mouth: chew food; esophagus: conduct food bolus to the stomach; b. Salivary glands contain salivary amylase, an enzyme for carbohydrate digestion. **31.3** Carbohydrates: mouth and small intestine; proteins: stomach and small intestine
31.4 Our intestines are very long. The long small intestine gives time for digestion (particularly carbohydrate digestion) to be completed and also absorption to occur. **31.5** The liver breaks down the medicine prior to its excretion, so it is necessary to keep taking it in order to maintain a certain level in the body. **31.6** Low-fiber, refined carbohydrates lead to poor health; high-fiber, whole-grain carbohydrates lead to good health. **31.7** Oils containing unsaturated fatty acids lead to good health. Fats containing saturated fatty acids and/or trans fatty acids, in particular, lead to poor health. **31.8** Vegetables supply nutrients and do not overtax the body's metabolism the way protein does. **31.9** Salts increase the osmolarity of blood and cause more water to be absorbed by the kidneys, leading to hypertension. **31.10** Whole grains, fruits, and vegetables, in general, supply vitamins in the diet.

Form Your Opinion

Page 631: 1. Birds are adapted for flight and a beak is light because it does not have teeth. The food a bird eats whether a seed or a fish does not need to be chewed. Cows are large animals that have few predators; they can take their time eating grass which requires much chewing and digestion. 2. I would rather be an herbivore so that I would not have to hunt and kill in order to eat. I could spend all my time eating and digesting my food. A carnivorous lifestyle does have its benefits as well: I could eat large meals high in protein and spend less time digesting my food. 3. When humans first evolved, they were not tool makers and didn't have the means to hunt and kill animals. As the brain increased in size, humans made tools and learned to use fire. When they migrated to Europe the weather turned cold, and because of their spears and greater intelligence, men could cooperate to hunt and kill large animal and use their skins for clothing.
Page 635: 1. To do a controlled experiment, Dr. Marshall needed two groups of volunteers; the test group would ingest a sample of *Heliobacter pylori* and the control group would ingest a sample that does not contain *Heliobacter pylori*. Each group is later tested for the presence of ulcers. 2. The absence of ulcer in the control group supports the hypothesis that *Heliobacter pylori* is the cause of ulcer in the test group.
Page 637: 1. Antibiotic therapy might kill off the bacteria that can help you digest lactose. 2. Pro-pill answer: I would prefer to take a pill that supplies enzymes because I love milk and other dairy products. If the intolerance could be managed with a simple pill I would take it over excluding some of my favorite foods from my diet. Pro-watch diet answer: I would prefer to manage my diet for lactose intolerance because I don't think a pill should be the answer to every ailment, and the pill may have side effects.
Page 643: 1. A person might have an unhealthy diet due to family dietary habits, lack of money, or a poor knowledge of a balanced diet. Schools could provide healthy foods in the dining room and should teach students the essentials of good nutrition. 2. Yes answer: Warning labels should be used because the government should protect us so we do not make poor food choices. No answer: Warning labels should not be used because education is a better protective measure than warning labels. The government should not be involved in every choice we make during our lifetimes.
Page 644: 1. Our society admires thinness and to avoid being seen as overweight, a person might develop an eating disorder. Advertisements encourage children to eat high-calorie foods and that could start them on the road to obesity. 2. You could offer emotional support for any underlying issue that may contribute to the disorder.

Testing Yourself

1. d; 2. a; 3. Life is sustained by a source of energy, and the digestive system provides the nutrients that provide energy to animals. 4. a; 5. d; 6. b; 7. b; 8. a. salivary glands b. esophagus c. stomach d. duodenum e. large intestine f. small intestine g. colon; 9. d because it contains the right enzyme, the right pH, and the right substrate; 10. e; 11. c; 12. d; 13. b; 14. b; 15. c; 16. b; 17. a. bile canals, b. hepatic artery, c. hepatic portal vein, d. bile duct e. central vein; 18. a; 19. e; 20. c; 21. b; 22. d; 23. The source of amino acids is of no consequence because the DNA of each cell specifies the types of proteins for that cell.

Thinking Scientifically

1. Pepsin, HCL, substrate (e.g., piece of cooked egg white), water. Omit the pepsin. If digestion still occurs, pepsin may not be the cause of digestion. 2. The use of a control group and a large number of participants makes the correlation more certain.

Put the Pieces Together

Page 647: 1. The digestive system provides the nutrients that allow all the systems of the body to acquire ATP and synthesize the molecules needed to maintain structure. 2. The placement of the liver between the digestive system and the circulatory system stresses that the liver monitors the quantity and purity of the molecules received from our food; it breaks down poisonous molecules and stores excess glucose. 3. Reducing the size of the stomach can reduce food intake by making us feel full sooner. Malnutrition can arise due to limited food intake or imbalance of the diet.

CHAPTER 32

Check Your Progress

32.1 Ventilation does not occur. **32.2** A counter flow mechanism ensures that blood is always exposed to a higher O_2 concentration; therefore, O_2 is continually taken up by blood. **32.3** Larger insects have a means of ventilating the tracheae, but external respiration (exchange of gases with incoming air), and internal respiration (exchange of gases in the tissues) comprise a single event in insects. **32.4** nasal cavity, pharynx, glottis, larynx, trachea, bronchus, bronchiole and alveoli of lungs. The path of air does not change when a person dives. However, note that air does not enter the body when a person dives but exchange continues in the lungs as long as possible. **32.5** Penguins can store air in the posterior air sacs. **32.6** When the spleen contracts, more red blood cells (more hemoglobin) enter the blood. This not only raises the amount of available oxygen, but the hemoglobin also helps control pH (see Section 32.7). **32.7** Oxyhemoglobin transports oxygen from the lungs to the tisssues. Most CO_2 is transported as the bicarbonate ion but some combines with hemoglobin forming carboaminohemoglobin. The globin portion of hemoglobin combines with H^+ forming HBH^+. Therefore hemoglobin plays a role in maintaining normal blood pH. Hemolgobin's essential function is transport of oxygen.

Form Your Opinion

Page 651: 1. (1) A hydra lives in an aquatic environment, which ensures a moist exchange surface. (2) Earthworms keep themselves moist

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by living in moist soil. (3) Fish live in aquatic environments and thus have moist exchange surfaces. (4) Insects have fluid filled tracheoles, which aid in exchange. (5) Mammals use the internal environment to keep exchange surfaces moist. 2. Fishes must use the motion of their mouths to power water over the gills in order receive oxygen from water. Humans can breathe through their noses; insects, earthworms and hydra also do not use their mouths to breathe. 3. Cellular respiration requires O_2 and gives off CO_2.
Page 655: 1. Yes answer: Smokers have a right to smoke, but should confine their smoking to non-public places since second hand smoke is a serious threat to anyone near a smoker. No answer: Smokers do not have a right to smoke and smoking should be outlawed because nonsmokers should not have to pay for the health costs of smoking. 2. Smokers suffer from bronchitis and often lung cancer and other types of cancer. 3. Cigarette manufacturers should be held responsible for providing cigarettes to the world, while friends and family members of smokers might bear some blame if they do not do their best to prevent smoking in their families.
Page 660: 1. Both activities bring pollutant irritants into the lungs and can cause conditions like chronic bronchitis and lung cancer. 2. An organic chemical could stimulate or inhibit a transduction pathway that ends with a transcription factor or activator that regulates gene activity. The end result of this altered gene regulation could be cancer. 3. Walking, household chores, climbing or descending a stairway, and heavy lifting would be troublesome for a person with emphysema.

Testing Yourself

1. c; 2. e; 3. a; 4. b; 5. b; 6. d; 7. b; 8. c; 9. c; 10. See Fig. 32.4; 11. b; 12. d; 13. f; 14. d; 15. a; 16. b; 17. e; 18. d; 19. left: a. rib cage up and out; b. diaphragm moves down; right: a. rib cage down and in; b. diaphragm moves up. 20. b; 21. b; 22. b; 23. d; 24. a; 25. e; 26. The shape of hemoglobin changes when the pH changes from near neutral in the lungs to slightly acidic in the tissues, and this causes it to unload its oxygen. 27. d; 28. b; 29. e; 30. The body has a limited capacity to store oxygen and has a better ability to store energy.

Thinking Scientifically

1. Fat metabolism results in acids that enter the bloodstream; a lower pH stimulates the respiratory center and causes increased breathing, which lowers the CO_2, but raises the O_2 blood level. Test the blood of a diabetic group and a normal group for these blood levels and compare the results of the tests. 2. A severed spinal cord prevents the medulla oblongata from communicating with the rib cage and diaphragm via the phrenic nerve and intercostal nerves.

Put the Pieces Together

Page 663: 1. The lungs have external exchange surfaces because air from the external environment enters the lungs. 2. The respiratory system excretes CO_2 which arises due to cellular metabolism. The digestive system rids the body of nondigestible remains which have never been a part of the body. 3. Hemoglobin (1) transports O_2 to the cells, (2) helps transport CO_2 to the lungs, (3) combines with H^+ and thereby helps buffer the blood.

CHAPTER 33

Check Your Progress

33.1 a. Urea is not as toxic as ammonia, and it does not require as much water to excrete; b. It takes less energy to prepare urea than uric acid. **33.2** No, the workings of the nephridia stay the same, regardless of respiration. The worm might gain less water from the environment because of its thicker skin and produce less urine as a result. **33.3** glomerular capsule, proximal convoluted tubule, loop of nephron, distal convoluted tubule, collecting duct, renal pelvis. **33.4** All small molecules enter the filtrate, and the tubule reabsorbs nutrients and salts into the blood as required to maintain normal blood concentrations. **33.5** It fine-tunes the reabsorption of sodium ions. **33.6** Fig. 33.6 shows how the kidneys regulate the pH of the blood: If the blood is basic, bicarbonate ions are excreted and not reabsorbed and H^+ is not excreted. If the blood is acidic, bicarbonate ions are reabsorbed and H^+ is excreted. Ammonia combines with H^+ to buffer it.

Form Your Opinion

Page 669: 1. Evolution would have followed this pathway: fresh-water fishes; to lobe-finned fishes in small bodies of freshwater on land; to amphibians that could locomote on land but had to return to fresh water to reproduce. 2. Excretion of ammonia is consistent with the early life of amphibians in the water; excretion of urea is consistent with their later life on land. You would predict that amphibians osmoregulate as their ancestors (freshwater fishes) did. 3. Humans osmoregulate by regulating the amount of salt and water in their blood as do freshwater fishes in that both have no way other than the kidneys to rid the body of salt.
Page 673: 1. I think that it is a person's own business if they want to take drugs, but that they must consider the consequences of doing so and be held responsible for any harm they might cause others.; therefore, I believe they should be tested by employers if other people would be harmed by their habit. 2. Jail might scare some people to give up drugs, however, addictions should be treated as illnesses and treated safely with medical supervision and with the support of drug/alcohol counselors. 3. Yes answer: Because of the risks associated with child drug use, including overdose, long term addictions, and death, I am a proponent of physicians testing children who raise suspicion of drug use. No answer: Children should not be tested for drug use. Children should be well-educated on the risks of drug use and monitored by parents and guardians to an extent that would prevent them from using drugs.
Page 676: 1. I might treat a dialysis patient that has to spend hours of the week in the hospital for hemodialysis like a "sick" person who needs special care. People have so many organ replacements today that I probably would not treat a person with a replaced bladder differently. 2. Except in cases of neglect or malpractice, I do not think that doctors, nurses, or technicians should be held responsible for unsuccessful hemodialysis. 3. If a person is able to perform the duties associated with a job and needs time off for medical treatment, some provisions should be made so they can be hired.

Testing Yourself

1. a; 2. d; 3. b; 4. b; 5. c; 6. See Fig. 33.3C; 7. c; 8. c; 9. a; 10. d; 11. These cells reabsorb most of the contents of the nephron and need increased surface area and energy to better pump molecules back into the blood. 12. e; 13.a,b,d; 14. a, b, d; 15. a, b; 16 c, b; 17. b; 18. a; 19. c,d; 20. a,b; 21. d 22. b; 23. d; 24 c; 25. a; 26. a; 27. The presence of salt in the blood causes more water to be passively reabsorbed, and the resulting increase in blood volume contributes to high blood pressure.

Thinking Scientifically

1. A microscopic study of their kidneys should reveal that they have a reduced glomerulus and a very long loop of the nephron. 2. Use the pump to increase the pressure of the blood passing through the tubing, increase the length of the tubing, and increase the rapidity with which the dialysis fluid passes through the apparatus.

Put the Pieces Together

Page 679: 1. Hormonal control of kidneys: (1) ADH regulates water reabsorption from collecting duct. (2) aldosterone promotes reabsorption of Na^+ at distal convoluted tubule, (3) ANH inhibits aldosterone secretion by adrenal cortex. 2. Blood pH is regulated through the carbonate buffer system in the blood and by the excretory and respiratory systems. The carbonate buffer system combines with acid or base to keep the pH constant; to raise pH the respiratory system excretes carbon dioxide and the kidneys excrete H^+ and reabsorb bicarbonate. The kidneys can also do the opposite to lower the pH when necessary. 3. The kidneys regulate the composition of the blood by excreting metabolites, and they regulate the salt-water balance so that the tonicity and volume of blood stays constant.

CHAPTER 34

Check Your Progress

34.1 They all send a chemical message that is received by a receptor and reception brings about a change in the cell's/organism's metabolism.
34.2 Whereas pheromones result in nerve messages to the brain; hormones are transmitted by the bloodstream and act on body cells directly; peptide hormones stimulate an enzyme cascade; and steroid hormones stimulate protein synthesis. **34.3** All of them represent passage of hormone by the bloodstream. All organs have receptors; otherwise, stimulation and negative feedback would not occur.
34.4 A child that is short in stature can receive growth hormone; increased bone length and muscle mass are expected as metabolism increases. Too much growth hormone can result in a giant with diabetes mellitus.
34.5 Pheromone to VNO to hypothalamus to anterior pituitary to thyroid gland and release of hormones.
34.6 Calcitonin causes the blood calcium to fall, and PTH causes it to rise. **34.7** Epinephrine and norepinephrine by the adrenal medulla. **34.8** Diabetes type 2 which occurs when the cells are not responsive to insulin can be due to a diet rich in sugar and fat. The diet leads to inactivity and obesity which is associated with diabetes type 2. **34.9** Winter; melatonin secretion starts earlier in the PM and discontinues later in the AM because the nights are longer.

Form Your Opinion

Page 691: 1. It is a prescribing physician's responsibility to explain any and all risks associated with treatment including hormone therapy. It is then a patient's choice whether or not to receive such therapies, having been made aware of the side effects. 2. Yes, it does make me uncomfortable because one can never know for sure if the "possible" negative effects will occur.
Page 694: 1. Sleeping in a room without a window seemed to bring on a degree of seasonal affective disorder for me. Without morning light to rouse me from sleep, I found myself sleeping later and later into the day. Though I attributed the change to a shift in melatonin, it could have been psychological also. 2. Night owl: I am a night person that likes to sleep in and go to bed in the early morning hours. This could be attributed to secretion of melatonin in the morning. Early bird: I am a morning person

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that likes to get up with the sunrise and get to bed early. This could be attributed to secretion of melatonin in the afternoon. 3. I would be hesitant to take a supplement such as growth hormone due to the associated risks and reported cases of diabetes and other problems. I would employ conventional methods of eating a healthy diet, exercising, and getting plenty of rest in order to improve my overall health.

Testing Yourself

1. d; 2. b; 3. a; 4. d; 5. d; 6. f; 7. b; 8. c; 9. a; 10. e; 11. Caffeine would increase the stress effect of epinephrine because cAMP, which drives the effect, would be slower to breakdown. 12. c; 13. c; 14. a; inhibits, b. inhibits, c. releasiing hormone, d. tropic hormone, e. target gland hormone; 15. d; 16. e; 17. c; 18. d; 19. c; 20. e; 21. d; 22. b; 23. a; 24. d; 25. b; 26. b; 27. High blood calcium causes the thyroid to secrete calcitonin, which leads to the uptake of calcium by bone. Calcium level drops and thyroid is no longer stimulated to release calcitonin.

Thinking Scientifically

1. Calcitonin, being a peptide hormone, stimulates the metabolism of osteoblasts to form bone utilizing calcium. 2. Use two groups of volunteers; one group consists of the "night owls" and the other group are "early birds." Collect blood samples from all volunteers when they are typically sleepy and when they typically wake up. If all goes well, the melatonin level rises earlier at night and lowers earlier in the day for the early birds.

Put the Pieces Together

Page 697: 1. Stress is a stimulus that causes the hypothalamus to send nerve impulses (nervous system involvement) to the adrenal gland which then releases epinephrine (endocrine system involvement). 2. Example: Low blood calcium is a stimulus that causes the parathyroid glands to secrete parathyroid hormone and this hormone brings about a rise in blood calcium level. The increase in blood calcium does away with the original stimulus and the parathyroid glands no longer release parathyroid hormone. 3. Biologists originally called the anterior pituitary gland the master gland because the anterior pituitary gland secretes many different hormones and some of these control the secretion of other endocrine glands. Later, biologists discovered that the hypothalamus secretes hormones that control the secretion of the pituitary gland and therefore it is the master gland.

CHAPTER 35

Check Your Progress

35.1 This asexual phenotype is the one that is already successful in the environment; the sexual production of various phenotypes is sure to produce at least one new phenotype that will be successful should the environment change the next season. **35.2** Sperm must be kept moist to survive. **35.3** They travel through the epididymis, the vas deferens, the ejaculatory duct, and, finally, the urethra. **35.4** The vagina receives the penis, which delivers the sperm; therefore, the sperm do not dry out. The egg is fertilized in the oviduct, where body fluids provide moisture. The embryo develops in the uterus, where it cannot dry out. **35.5** To produce the female sex hormones (estrogen and progesterone) and to produce an oocyte. **35.6** Birth control pills and any various other hormone delivery methods (patch, injections, implant). **35.7** Lancelets develop quickly into a free-living aquatic larva; birds develop inside a shelled egg and need a food source (the yolk); human embryos develop in the uterus and get nutrients from the mother. **35.8** establishment of the germ layers during gastrulation **35.9** The notochord is formed from mesoderm and is a supportive structure that lies underneath the neural tube, which is formed from ectoderm. In vertebrates, the notochord is replaced by the vertebral column, and the neural tube becomes the nervous system. **35.10** Chemical signals tell cells how they are to behave and how they will become specialized. **35.11** Induction causes cells to move and form a particular structure. **35.12** To make internal development possible; the chorion is a part of the placenta, for example. **35.13** Sponges have the cellular level of organization; cnidarias (e.g., hydras) have the tissue level of organization; flatworms (e.g., planarian) have the organ level of organization; and all animals thereafter have the systems level of organization. **35.14** The systems are just about fully formed during embryonic development, even though the embryo is tiny and weighs little. During fetal development there is weight gain and and refinement of structures. **35.15** Before birth, the placenta supplied the needs of the fetus.

Form Your Opinion

Page 701: 1. When the relationship is monogamous, males are fairly assured that the offspring is theirs. Females exercise choice by selecting as mates, males that appear to evolutionarily fit. When the relationship is not monogamous, males become sexually aggressive and females become defensive and only let down their defenses when they choose to. 2. Each sex wants their particular alleles to be passed on to the next generation. 3. Traditionally, before marriage males chase females and females withhold sexual favors. This might cause males to become deceptive and make the female believe they are interested in marriage when they are not interested. It might make the female be the first to break off a relationship that does not seem to be headed toward marriage. To test the hypothesis, I would take a survey of females to determine how many broke off a relationship because marriage did not seem in the offing.
Page 708: 1. It is evolutionary beneficial for sex to be a powerful motivator in order to perpetuate a species. It is personally disadvantageous because of the risk of sexually transmitted infections such as those discussed in this passage. Women who reproduce earlier than planned may have to give up plans for a career or will find it more difficult to pursue a career while caring for children. 2. Social consequences that might result from having a non-treatable sexually transmitted disease (STD) range from economical to interpersonal. Treatment for STDs and lost work time represent an economic consequence. Socially, infertility and the risk of transmission to a partner could make a person less desirable as a long-term mate. 3. Yes answer: I do approve of allowing young girls to receive the HPV vaccine. I think the benefits of decreasing the risk of cervical cancer are enormous and it is no different than a vaccine to protect a child from any other disease. No answer: I do not approve of allowing girls as young as 9 to receive the HPV vaccine. I think that a girl should be presented with this option at an age deemed appropriate by a parent or physician in the early teen years.
Page 709: 1. sperm donor- because the donor is the genetic parent of the child. egg donor—because the donor is the genetic parent of the child. surrogate mother—because she carries a child and is ultimately responsible for its being born a healthy, viable child. contracting mother—because of legal agreement to care for the child produced from the pregnancy of the surrogate mother. contracting father—because of legal agreement to care for the child produced from the pregnancy of the surrogate mother. 2. Pros: successful pregnancy, overcoming reproductive challenges. Cons: Multiple failed attempts at pregnancy, cost of procedures, pain surrounding hormone injection, legal issues surrounding surrogates or sperm/ egg donations, emotional wear and tear. For couples who have struggled with reproducing and are forced to utilize these technologies to produce an offspring, the benefits outweigh the drawbacks. 3. Legislation should regulate which of the "5 potential parents" listed above actually does have the best claim to the child. Decisions should be made beforehand, like in an adoption, whether or not to make a sperm or egg donor available to a child later in life. In addition, the use of reproductive technology should be limited in cases like the "Octo-mom" where a large single parent family exists; thus creating the risk that the children will be neglected or the single parent will be unable to support all of the children.

Testing Yourself

1. e; 2. c; 3. Sexual reproduction produces variations among the offspring and one of these may be phenotypes that can deal with the new conditions. 4. b; 5. See Fig. 35.2; 2 6. a; 7. c; 8. b; 9. A high blood testosterone level shuts down the anterior pituitary production of gonadotropic hormones, reducing sperm production. 10. c; 11. b; 12. b; 13. c; 14. d; 15. zygote, cleavage, morula, blastula, gastrula, neurula.16. a. chorion (gas exchange), b. amnion (protection), c. embryo, d. alllanois (umbilical blood vessels), e. yolk sac (blood cell formation) f. and g. (placenta is area of exchange with mother); 17. c; 18. d

Thinking Scientifically

1. Testosterone causes increased cell division in the prostate. Microscopically, observe the effect of testosterone on cells taken from the prostate.
2. Progesterone maintains the uterine lining, and if the placenta doesn't begin producing it when it should, a woman could lose the embryo embedded in the lining.

Put the Pieces Together

Page 723: 1. The human male reproductive organs are adapted to the production and storage of sperm in the temperature-regulated scrotum, secretion of protective fluids for the safe transfer of mature sperm, as well as direct deposit of seminal fluids into the female reproductive organs. Internal development of a fetus in amniotic fluid shows that human development is still tied to an aquatic environment. 2. Animals go through the same developmental stages and this would not develop similarly if they were not related and descended from a common ancestor. 3. Many genes are active only during development and they get turned off as the organism matures.

CHAPTER 36

Check Your Progress

36.1 The population, habitat, community, and ecosystem levels are all affected. **36.2** Density. **36.3** Reproductive because the age structure diagram would resemble a stable population. **36.4** Exponential growth would occur until competition for resources slowed the population growth to meet the carrying capacity. **36.5** Severe natural disasters (such as hurricanes) and weather-related food shortages are two examples. **36.6** Competition for food and habitat resources are two examples. **36.7** Equilibrium species, because of their large body size, relatively long life span, and the few offspring produced per deer each year. Deer are exploding because they have no predators and are able to live in the vacinity of people. Gorillas prefer a restricted environment that is shrinking and they form small populations. **36.8** It would lengthen the doubling time, because the deer would add fewer offspring to the population.

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Form Your Opinion

Page 736: 1. In efforts to protect individual species, we pay special attention to preserving their habitats. As such, protecting "hotspots" would essentially be a means to protect many organisms and their homes. However, if "hotspots" are not home to any endangered species, we should still preserve individual species that inhabit other locations. 2. Yes answer: Though it is a controversial issue, I support the preservation of cheetahs in zoos if it can help increase the population. Continued monitoring of genetic diversity is essential. Perhaps cheetahs can be bred in zoos for a period of time and later strategically released onto protected lands, I see the use of zoos as beneficial. No answer: I think that efforts should be made to preserve cheetahs in their natural environment and not in the captivity of a zoo where they are unable to run freely and hunt food, skills that are characteristic of cheetahs in the wild. 3. Although it is important for our own needs to preserve specific species and natural environments, we should not neglect unique endangered species. Minor changes in ecosystems can have widespread and unpredictable effects. The loss of unique endangered species might alter our planet in ways we did not anticipate. Because we are the cause of much of the loss of habitat, pollution, and introduction of non-native plants or animals that causes endangering of species, we should make every effort to preserve as much of the natural environment as possible. **Page 738:** 1. Yes answer: Considering that our current way of living and reproducing is not sustainable, families in the US are acting selfishly when they have more than two children. This is selfish behavior because it has little regard for the future and the impact we are making on our planet that will be detrimental, and possibly preventative, of generations of human beings to come. No answer: I believe families in the US that have more than two children are not acting selfishly if they make efforts to have minimal impact on the environment. It is more important, no matter the size of families, that people in the US pay attention to energy use and exploitation of resources in order to have less negative impact on the planet. 2. Sustainability would provide a quality of life for future generations that is equal to the current conditions. This would help the economy by providing a steady source of materials for production, thus stabilizing prices in the long run. 3. The United States should hold itself, along with other countries, to the same standards with regard to environmental impact. More developed countries tend to have a greater impact on the environment and should be keenly aware of the predicament this puts the planet in for the future. The U.S. should certainly reduce its environmental impact while expecting other countries to do the same. The benefits for the planet and the future of humanity depend upon our responsible management of resources and preservation of the planet we inhabit today.

Testing Yourself

1. d; 2. d; 3. b; 4. d; 5. b; 6. a; 7. b; 8. a; 9. c; 10. The offspring of a plant that reproduces by runners would remain near the parent. The offspring of a plant that reproduces by windblown seeds could be taken far away from the parent. 11. See Fig. 36.4B; 12. c; 13. a; 14. b; 15. c; 16. a. density independent factor, b. density dependent factor; 17. c; 18. d; 19. When the environment is unstable due to density-independent and density-dependent factors, a few of the many small, uncared for offspring might have a better chance of dispersal to a favorable environment. 20. a; 21. a; 22. c; 23. d; 24. e.

Thinking Scientifically

1. You might hypothesize that the right whale has only one offspring per reproduction and chances of death before maturity are good. The right whale begins reproducing well after maturity, and reproduces infrequently. To test your hypothesis, you would have to observe a captive population or tag individuals in the wild and observe them from a distance. 2. Determine the original normal flow of the river and maintain the flow as close to normal as possible.

Put the Pieces Together

Page 741: 1. A moderate population size in desirable because it strikes a balance between the negative aspects of very large and very small populations. Very large populations over-exploit the resources of their environment, and might become extinct due to lack of resources. Very small populations lose genetic variability and run the risk of extinction from disease associated with inbreeding, infectious diseases, or extreme environmental changes (flood, drought, etc). 2. We should definitely be concerned about how the growing U.S. population affects consumption and sustainability of our population. Eventually, our non-renewable resources will run out and renewable resources will not be able to keep up with our consumption. If we persist in a trend of increased population without regard to the environmental impact we are making, we run the risk of not only running out of natural resources, but also destroying ecosystems due to pollution and overdevelopment. 3. As demonstrated in Figure 36.3C, more women entering than leaving their reproductive years means that births will continue to increase population over time. A population that consists of more young members than old lends itself to growth that is not balanced out by deaths. In populations with a balance between older and younger members, stabilization occurs.

CHAPTER 37

Check Your Progress

37.1 Because all members of the colony have the same mother, they would all inherit the gene, and the colony would die out as tunnel excavating ceased. **37.2** Observe a mole rat in its colony from the time of birth and see if efficiency in building tunnels improves over time. **37.3** Operant conditioning because the younger workers would be rewarded for tunnel work. **37.4** One reason animals are territorial is to forage for foood. **37.5** No, because all mole rats are close relatives. **37.6** Raise birds that are unable to perform this behavior and then compare the fitness of birds that sing to mark their territory with those that do not.

Form Your Opinion

Page 749: 1. Yes answer: Evolutionary principles should be applied to human reproductive behavior. Like other animals, humans demonstrate sexual selection and the mating behavior of both males and females indicates a preference towards selecting the partner with the optimal fitness. No answer: I believe evolutionary principles should not be applied to human reproductive behavior, since our complex culture influences reproduction in ways that are not possible in other animals. For example, selection of males based on financial security is unique to humans. In addition, our technological advances can help "less fit" individuals survive and reproduce. 2. I have observed many examples that support male competition for females and female choice based on financial stability. On average, men marry and have children with younger women. Traditional dating behavior follows a trend of a man impressing a woman in order to "earn the privilege" of mating and reproduction. **Page 754:** 1. My experience with dogs leads me to suggest that dogs do feel affection for their owners, anger demonstrated through aggression, excitement for food and play, shame when admonished for undesirable behavior, and mourning at the permanent loss of a playmate (another animal) or human companion. 2. With regard to pets, I would take care not to provoke aggression, and reward them and praise them for desirable behaviors. In nature, I would also refrain from provoking aggressive or territorial behavior in an animal, bearing in mind that the emotions of wild animals are tied closely to instincts. 3. Yes answer: The conclusion that animals do have emotions makes them seem closer to human beings, thus making eating an animal nearly cannibalistic in nature. Though I tend to associate emotions more with pets than animals raised for food, I would reconsider eating meat with evidence that all animals display emotions. No answer: I would continue to be an omnivore even with conclusions that animals have emotions. I think that animal emotions differ from human emotions and are tied largely to instinctual response to stimuli.

Testing Yourself

1. c; 2. b; 3. e; 4. c; 5. c; 6. b; 7. See Fig. 37.3; 8. a; 9. d; 10. c; 11. c; 12. a; 13. Because females produce few gametes and have few offspring during their lifetime, they place an emphasis on quality of offspring. Because males produce many gametes all the time, they place an emphasis on quantity of offspring. 14. d; 15. e; 16. a; 17. They would be increasing their inclusive fitness when they help their parents at a time they cannot be reproducing themselves. Reciprocal altruism would ensure that they will successfully reproduce when the time comes. 18. a; 19. c; 20. b; 21. d

Thinking Scientifically

1. Mate the two types of rats and test how the offspring react to limburger cheese. If they show an intermediate response, such as being willing to approach the cheese but still not eating it, then the behavior may be genetically controlled. 2. Observe sentry behavior more closely. Recent observations have shown that sentries are the first ones to reach safety when a predator is spotted, and meerkats only serve as sentries after they have eaten.

Put the Pieces Together

Page 757: 1. Natural selection favors the successful competitor for territory while the losing animal(s) may not survive to reproduce without having a territory. 2. The idea that behavior is largely response to stimulus, and that some responses yield increased fitness might be offensive to people who prefer to think of behavior as learned and correlated with cognitive choice. 3. Crickets make calls to attract mates. This behavior is risky, and can lead to predation. However, the benefits of attracting a mate have overcome the risk evolutionarily, since natural selection has perpetuated populations of crickets that make calls for mates.

CHAPTER 38

Check Your Progress

38.1 Decomposers release chemicals that make dead material smell and taste unpleasant to many other animals. Some animals, such as scavengers, are not repulsed, however. **38.2** When scavengers eat decomposing meat, they are also eating the decomposers that are devouring the food source before them. **38.3** Parasites but not decomposers use nutrients meant for the host organism. If the host

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dies, the parasite is also threatened with death. **38.4** Study the feeding behavior of a remora when not attached to a shark. If it can survive independently, it is more likely commensalistic with the shark. **38.5** The protozoans are provided with food and habitat. **38.6** Succession would essentially stop. Most chemical nutrients would be tied up in dead organisms making new growth very limited. **38.7** Only autotrophs can use an outside energy source to produce organic food required by all the biotic components of an ecosystem. **38.8** The inorganic chemicals are taken up by plants and the recycling of chemicals in an ecosystem begins again. **38.9** Bacteria and fungi of decay. **38.10** None; ecological pyramids do not include decomposers. This is one of their shortcomings. **38.11** The reservoir and the exchange pool are abiotic. **38.12** Decomposers gradually break down the bones making phosphate ions and other chemicals available. **38.13** Nitrification. **38.14** It would decrease greenhouse emissions and reduce the threat of a rise in global temperature.

Form Your Opinion

Page 765: 1. In both the predator-prey and parasite-host relationships, one of the individuals (predator and parasite) benefits more than the other (prey and host). The difference is that in a predator-prey relationship, the death of prey is guaranteed, while the death of a host is not always the case in parasitism. 2. HIV cannot currently be effectively vaccinated against, and even if caught early, remains incurable. H1N1 can be vaccinated against and is also treatable in certain stages of illness. HIV is a retrovirus capable of producing DNA from its RNA within a host cell, thus taking over the host entirely over time. 3. A pollinator coevolves with a flower such that the flower evolves to attract the pollinator and the pollinator adapts to feed from the flower (i.e. long proboscis when the flower is deep). This coevolution takes place in the same "direction" the flower to be pollinated and the pollinator in order to feed. Coevolution between parasite and host differs in that hosts evolve under selective pressure to avoid being infected by parasites, while parasites evolve under pressures to evade host defenses. The parasite and host are evolving in different "directions"- the host to avoid the parasite and the parasite to overcome attempts to be avoided. **Page 769:** 1. Food chains will be altered; killing off large predators or the introduction of alien species will create new predator-prey relationships, potentially exterminating some prey. Each minor change to the area has trickle down effects that touch not only the animals, but plants as well as abiotic resources. 2. Small areas, cut off from former connections lose species, altering predator-prey relationships and causing other potentially disruptive changes throughout an environmental system.

Testing Yourself

1. c; 2. e; 3. e; 4. a; 5. c; 6. b; 7. d; 8. Will the area be able to meet the niche requirements of this predator? (see Fig. 38.7); 9. b; 10. a; 11. b; 12. e; 13. See Fig. 38.8A; 14. c; 15. d; 16. c; 17. c; 18. b; 19. c; 20. d; 21. d; 22. No; Photosynthetic species are always at the first trophic level and nonphotosynthetic species are always at a higher level.

Thinking Scientifically

1. Observe the birds carefully to see if they differ in ways suggested by Figure 38.7. 2. Measure and fill a large container with water from the pond. Add measured amounts of phosphate slowly over several days or months, and when you see growth, calculate the amount of phosphate you need for the pond.

Put the Pieces Together

Page 779: 1. Three populations would be students, faculty, professors: (1) Students interact with professors for the exchange of information, mostly professor to student. Professors interact with faculty for record keeping, financial exchanges etc. (2) Faculty must not be too small to meet the needs of students and professors, but also not too large to be sustainable financially. (3) With a small student body, fewer faculty and staff are needed and able to be sustained. A larger student body bears the necessity of a larger faculty and staff of professors who are then financially sustainable through more incoming tuition from students. 2. The human population is dependent on natural resources and people should definitely work to preserve the natural environment in order to maintain the resources needed for life. Many of our actions fail to preserve the natural environment because we exploit natural resources, alter the habitats of many organisms, and create large amounts of waste at a rate unmatched by our efforts to replenish and repair the damage we do.

CHAPTER 39

Check Your Progress

39.1 temperature and rainfall **39.2** Look at the distribution of landmasses in this chapters various maps. They are shifted toward the northern latitudes. **39.3** No, the winds are weaker than usual. **39.4** Rain forests receive much rainfall and solar energy; therefore, they produce enough food for many organisms. The various plants in a tropical rain forest provide many different types of niches for many different organisms. These two factors help account for why tropical rain forests exhibit species richness. **39.5** It would be difficult to simulate the winter of a tundra and to stock it with animals as large as caribou. **39.6** Coniferous trees are soft wood. **39.7** No, you need the rich soil, the understory plants, and the many animals. **39.8** No, prairies receive less rainfall than do forests. **39.9** Grasses and scattered trees. **39.10** Cold. **39.11** Epiphytes. **39.12** Wetlands. **39.13** Euphotic.

Form Your Opinion

Page 787: 1. The major groups of organisms can be found on all continents because the present-day land masses used to be a supercontinent. Types of organisms can vary between continents depending upon when the animals evolved relative to the separation of the continents. 2. Because of the age of the man, he most likely traveled across sea or ice but did not make his way to Greenland from Siberia via Beringia since this land bridge is believed to have been exposed during the last ice age 12,000 to 20,000 years ago.
Page 794: 1. (1) The effect of the barometric pressure over the Southeast Pacific and the Indian Ocean upon weather on the coasts of the United States is an example of this connection. (2) Everything is truly connected to everything else if we trace carbon through its cycle: essentially all of the carbon present even in the bodies of human has been present in many other molecules since carbon first appeared in the atmosphere. Carbon makes its way from the atmosphere into soil, plants, animals, and water (etc). 2. Prior to the completion of a dam in 1970, the annual flooding of the Nile River left behind fertile silt capable of sustaining agriculture in Egypt. A small flood or no flood at all would result in famine for this area. The annual flood was a dangerous event, but without it, Egypt's farming would have been impossible.

Testing Yourself

1. b; 2. e; 3. See Fig. 39.2B; 4. c; 5. b; 6. a; 7. Hot air from the equator moves toward the poles. 8. d; 9. d; 10. a; 11. a; 12. a; 13. d; 14. e; 15. d ; 16. b; 17. Decomposers use up any available oxygen, leaving none for the fish. 18. b; 19. c; 20 c; 21 e; 22. d; 23. e; 24. Sea level would be too deep for previous estuaries to exist, and new ones may not develop further inland due to development of coastal regions.

Thinking Scientifically

1. You will be able to see if a rising global temperature affects the distribution of biomes in the biosphere. 2. Coral houses microscopic algae and if the dirty water blots out the sun, the algae will die.

Put the Pieces Together

Page 797: 1. (a) Squirrels: small herbivorous animals which are behaviorally adapted to collect and store foods (like nuts) in order to have nourishment through the winter. The thick fur coats of squirrels are also adaptations to colder winters in the temperate deciduous forest. (b) Sloths: slow-moving within the trees, these animals are adapted to expend very little energy which coincides with the slow digestion of fruit and leaves carried out by their specially adapted digestive system. Since sloths use very little energy, they do not need to eat much. (c) Squid: have a very large eye for hunting in the extremely low light levels of the deep sea as well as the ability to maneuver through water via jet propulsion, making them mostly fast-moving creatures. 2. Due to the protection offered by the mangrove swamp, it would certainly benefit a human population to restore a mangrove swamp over a housing development that would likely see damage or devastation shortly after it was rebuilt. Hurricane damage can be avoided if we resist the urge to build homes as close to the shore as possible, and instead guard our shores with protective barriers such as mangrove forests. 3. Five negative effects of the human population on the oceans: Pollution from developed areas including sewage, toxic chemicals, insecticides, and detergents invades the ocean and is carried by the tides throughout the ocean where they can invade the habits of animals, or even be consumed by them. Burning of fossil fuels has increased acidity of rain and lakes to the detriment of forests and freshwater inhabitants. Litter and improperly disposed trash is trapping and being eaten by animals, killing them. Dredging the ocean floor with heavy nets and chains as a method of fishing disturbs the ocean floor habitat and kills many non-target fish/animals in the process (by-catch). Drilling for oil sometimes results in oil spills and causes long-term damage to the oceans, killing animals and destroying shoreline habitats.

CHAPTER 40

Check Your Progress

40.1 To preserve natural resources/biodiversity. **40.2** Ecosystem-level conservation has the potential to save a large number of species instead of just one. **40.3** Reduced aquatic biodiversity would limit the amount and types of seafood we consume. **40.4** Native animals and plants in their natural environment. **40.5** A large number of people living and building structures a long the coast. **40.6** They reduce biodiversity by causing other species to become extinct. **40.7** Global climate change because it will affect so many species. **40.8** Overexploitation. **40.9** Disease. **40.10** Metapopulation. **40.11** To return the area to its former state (i.e., a thriving ecosystem). **40.12** Primarily by preserving ecosystems and areas of species richness. **40.13** Preservation of natural resources and less pollution of the enviironment. **40.14** Famers can grow salt tolerant plants and otherwise use drip

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irrigation; industry can use air instead of water for cooling purposes **14.15.** Use other means of controlling pests rather than pesticides such as polyculture and biological pest control; use drip irrigation to water plants, saving water; use legumes to fertilize land insted of artificial fertilizers.

Form Your Opinion

Page 808: 1. Scientists could use artificial selection to breed members of species that display adaptive traits or behaviors that make them tolerable of climate change in order to help these species survive, essentially fast forwarding what might occur via natural selection over a longer period of time. 2. Extinction could occur even when plenty of food is available to small, weak members of a population due to the ease with which predators can feed on the smaller, weaker members of a population. 3. Though the temperature might be suitable for survival, the new surroundings could be home to predators not previously encountered by a species and may not contain an adequate food supply. The ecosystem in which the species is adapted to living is suitable due to many factors, not temperature alone.
Page 812: 1. Hybridizing essentially creates an animal that is not technically an original member of the nearly extinct species. Mixing in a new animal creates a new species, creating a risk of extinction among the pure species, an unfortunate method of preservation that can contribute to the loss of characteristics unique to the nearly extinct species. 2. Zoos and hatcheries must sometimes maintain a species because its numbers are too low for it to sustain itself naturally. The habitat is unable to meet the needs of the species and the species is unable to adapt to changes occurring in the habitat. 3. Yes. If the habitat was maintained to begin with, rather than in need of restoration, the species would be able to sustain itself naturally. The ecosystem likely supports a range of species of plants and animals that would benefit from efforts to maintain it rather than efforts to maintain individual species outside the natural environment for reintroduction to nature.

Testing Yourself

1. e; 2. a; 3. b; 4. b; 5. The added shrimp pushes the salmon to a higher place in the food pyramid, indicating that less energy is now available to them. 6. d; 7. e; 8. e; 9. e; 10. e; 11. a; 12. e; 13. d; 14. e; 15. b; 16. Food webs show many connections between different populations. 17. b; 18. c; 19. e; 20. d; 21. b; 22. b

Thinking Scientifically

1. Overharvesting reduces genetic diversity due to the bottleneck effect. As with the cheetah, determine how many loci are now homozygous. 2. Besides having produced a population with limited genetic diversity, none of the problems that brought the species to near extinction (see Sections 40.5–40.9) have been solved.

Put the Pieces Together

Page 819: 1. Instead of increasing the manipulation of plants and animals via biotechnology, I would rather see the needs of the growing population met with an alternative method. For example, if the human population was to shift to growing and consuming locally, fostering crops suitable to the environment in which they are grown rather than the most popular crops that yield the best profits, we could use nature to our advantage to feed the growing population. 2. Emphasis on renewable energy is necessary in order to achieve sustainability because nonrenewable energy sources are quickly being depleted and cannot ever be replaced. I agree with this emphasis. It is important for people to understand that the sources of energy we are accustomed to using cannot feasibly be utilized long term and will, sooner than later, run out.
3. Yes, I am willing to pay extra for organic foods. The societal benefits of reduced pesticide and herbicide use include reduction of pollution of water and air and decreased side effects on non-target populations of animals/insects. 4. Yes answer: I agree that the human population should stabilize and that each couple should only replace itself because resources are finite. No answer: I do not agree that human population should stabilize and believe technology will always find a way to increase the availability of resources.

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Glossary

A

abscisic acid (ABA) Plant hormone that causes stomata to close and initiates and maintains dormancy. 474
abscission Dropping of leaves, fruits, or flowers from a plant. 441, 474
acceptor end In tRNA, the end that binds to the amino acid. 200
accessory fruit Fruit, or an assemblage of fruits, whose fleshy parts are derived from tissues other than the ovary (e.g., strawberry). 497
acetylcholine (ACh) (uh-seet-ul-koh-leen) Neurotransmitter active in both the peripheral and central nervous systems. 530
acetylcholinesterase (AChE) (uh-seet-ul-koh-luh-nes-tuh-rays) Enzyme that breaks down acetylcholine bound to postsynaptic receptors within a synapse. 531
acid Molecules tending to raise the hydrogen ion concentration in a solution and to lower its pH numerically. 36
acoelomate Animal that has no body cavity (i.e., tapeworm). 387
actin (ak-tin) One of two major proteins of muscle; makes up thin filaments in myofibrils of muscle fibers. (See myosin.) 582
actin filament Cytoskeletal filaments of eukaryotic cells composed of the protein actin; also refers to the thin filaments of muscle cells. 78
action potential Electrochemical changes that take place across the axomembrane; the nerve impulse. 528
active site Region on the surface of an enzyme where the substrate binds and where the reaction occurs. 90
active transport Use of a plasma membrane carrier protein and energy to move a substance into or out of a cell from lower to higher concentration. 98
adaptation An organism's modification in structure, function, or behavior suitable to the environment. 16
adaptive radiation Evolution of several species from a common ancestor into new ecological or geographical zones. 278
addiction Physiological and psychological need for a habit-forming drug. 542
adenosine Portion of ATP and ADP that is composed of the base adenine and the sugar ribose. 58
adenosine diphosphate (ADP) (ah-den-ah-seen dy-fahs-fayt) Nucleotide with two phosphate groups that can accept another phosphate group and become ATP. 58
adenosine triphosphate (ATP) (ah-den-ah-seen try-fahs-fayt) Nucleotide with three phosphate groups. The breakdown of ATP into ADP + P makes energy available for energy-requiring processes in cells. 58
adhesion Attachment of cells, as when water adheres to the vessel walls of plants. 33
adipose tissue Connective tissue in which fat is stored. 511
adrenal cortex (uh-dree-nul kor-teks) Outer portion of the adrenal gland; secretes mineralocorticoids, such as aldosterone, and glucocorticoids, such as cortisol. 690
adrenal gland (uh-dree-nul) An endocrine gland that lies atop a kidney, consisting of the inner adrenal medulla and the outer adrenal cortex. 690
adrenal medulla (uh-dree-nul muh-dul-uh) Inner portion of the adrenal gland; secretes the hormones epinephrine and norepinephrine. 690
adrenocorticotropic hormone (ACTH) (uh-dree-noh-kawrt-ih-koh-troh-pik) Hormone secreted by the anterior lobe of the pituitary gland that stimulates activity in the adrenal cortex. 686
adult stem cells Cells in a mature body that have the ability to divide; found in red bone marrow. 145
aerobic Phase of cellular respiration that requires oxygen. 125, 323
afterbirth Placenta and the extraembryonic membranes, which are delivered (expelled) during the third stage of birth. 720
age structure diagram In demographics, a display of the age groups of a population; a growing population has a pyramid-shaped diagram. 731
aggregate fruit Fruit developed from several separate carpels of a single flower. 497
aldosterone (al-dahs-tuh-rohn) Hormone secreted by the adrenal cortex that decreases sodium and increases potassium excretion; raises blood volume and pressure. 675, 691
alga Type of protist that carries on photosynthesis; unicellular forms are a part of phytoplankton, and multicellular forms are called seaweed. 335
alien species Nonnative species that migrate or are introduced by humans into a new ecosystem; also called exotics. 806
alkaloids Bitter-tasting nitrogenous compounds that are basic (e.g., caffeine). 482
allantois (uh-lan-toh-is) Extraembryonic membrane that contributes to the formation of umbilical blood vessels in humans. 715
allele (uh-leel) Alternative form of a gene; alleles occur at the same locus on homologous chromosomes. 173
allergy Immune response to substances that usually are not recognized as foreign. 622
allopatric speciation Origin of new species between populations that are separated geographically. 276
alloploidy Polyploid organism that contains the genomes of two or more different species. 279
alternation of generations Life cycle, typical of plants, in which a diploid sporophyte alternates with a haploid gametophyte. 160, 354
alternative mRNA splicing Variation in pre-mRNA processing resulting in different mRNAs and different protein products. 199
altruism Social interaction that has the potential to decrease the lifetime reproductive success of the member exhibiting the behavior. 750

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alveolus (pl., alveoli) Air sac of a lung. 654

Alzheimer disease (AD) Brain disorder characterized by a general loss of mental abilities. 538

amino acid Organic molecule having an amino group and an acid group, which covalently bonds to produce peptide molecules. 53

ammonia Colorless gas that has a penetrating odor and is soluble in water. 666

amniocentesis Procedure in which a sample of amniotic fluid is removed through the abdominal wall of a pregnant woman. Fetal cells in it are cultured before doing a karyotype of the chromosomes. 181

amnion (am-nee-ahn) Extraembryonic membrane that forms an enclosing, fluid-filled sac. 715

amniotic egg Egg that has an amnion, as seen during the development of reptiles, birds, and mammals. 402

amoeboid Cell that moves and engulfs debris with pseudopods. 339

amphibian Member of a class of vertebrates that includes frogs, toads, and salamanders; they are still tied to a watery environment for reproduction. 401

ampulla Expansion at the end of each semicircular canal that houses the receptors for rotational balance. 562

amygdala (uh-mig-duh-luh) Portion of the limbic system that functions to add emotional overtones to memories. 538

anabolism Metabolic process by which larger molecules are synthesized from smaller ones; anabolic metabolism. 135

anaerobic Growing or metabolizing in the absence of oxygen. 125

analogous structure Structure that has a similar function in separate lineages but differs in anatomy and ancestry. 257, 303

anaphylactic shock Severe systemic form of allergic reaction involving bronchiolar constriction, impaired breathing, vasodilation, and rapid drop in blood pressure with a threat of circulatory failure. 622

anchoring junction Junction between animal cells that attaches the cells to each other. 99

ancestral character Structural, physiological, or behavioral trait that is present in a common ancestor and all members of a group. 298

anemia (uh-nee-mee-uh) Inefficiency in the oxygen-carrying ability of blood due to a shortage of hemoglobin. 600

aneuploid Individual whose chromosome number is not an exact multiple of the haploid number for the species. 162

angiogenesis (an-jee-oh-jen-uh-sis) Formation of new blood vessels, an event that occurs to promote the enlargement of a tumor. 153, 223

angiosperm Flowering plant that produces seeds within an ovary, which develops into a fruit; therefore, the seeds are covered. 365

angiotensin II Hormone produced from angiotensinogen (a plasma protein) by the kidneys and lungs; raises blood pressure. 675

animal Multicellular, heterotrophic organism belonging to the animal kingdom. 15

annelid Member of a phylum of invertebrates that contains segmented worms, such as the earthworm and the clam worm. 392

annual ring Layer of wood (secondary xylem) usually produced during one growing season. 442

anorexia nervosa (a-nuh-rek-see-uh nur-vohsuh) Eating disorder characterized by a morbid fear of gaining weight. 644

anterior pituitary (pih-too-ih-tair-ee) Portion of the pituitary gland that is controlled by the hypothalamus and produces six types of hormones, some of which control other endocrine glands. 686

anther In flowering plants, pollen-bearing portion of stamen. 491

anthropoid ancestor Group of primates that includes monkeys, apes, and humans. 415

antibody (an-tih-bahd-ee) Protein produced in response to the presence of an antigen; each antibody combines with a specific antigen. 601

antibody-mediated defense Specific mechanism of defense in which plasma cells derived from B cells produce antibodies that combine with antigens. 600

anticodon (an-tih-koh-dahn) Three-base sequence in a transfer RNA molecule base that pairs with a complementary codon in mRNA. 200

anticodon end In tRNA, the end that binds to mRNA. 200

antidiuretic hormone (ADH) (an-tih-dy-uh-ret-ik) Hormone secreted by the posterior pituitary that increases the permeability of the collecting ducts in a kidney. 674, 686

antigen (an-tih-jun) Foreign substance, usually a protein or a polysaccharide, that stimulates the immune system to produce antibodies. 601, 615

antigen-presenting cell (APC) Cell that displays the antigen to the cells of the immune system so they can defend the body against that particular antigen. 616

antigen receptor Receptor proteins in the plasma membrane of immune system cells whose shape allows them to combine with a specific antigen. 616

antioxidant Substances, such as vitamins C, E, and A, which defend the body against free radicals. 642

aorta (ay-or-tuh) Major systemic artery that receives blood from the left ventricle. 592

aortic body Sensory receptor in the aortic arch sensitive to the O_2, CO_2, and H^+ content of the blood. 657

apical dominance Influence of a terminal bud in suppressing the growth of axillary buds. 470

apical meristem In vascular plants, masses of cells in the root and shoot that reproduce and elongate as primary growth occurs. 436

apoptosis (ap-uh-toh-sis, ahp-) Programmed cell death involving a cascade of specific cellular events leading to death and destruction of the cell. 152

appendicular skeleton (ap-un-dik-yuh-lur) Portion of the skeleton forming the pectoral girdles and upper extremities and the pelvic girdle and lower extremities. 572

appendix In humans, small, tubular appendage that extends outward from the cecum of the large intestine. 611

aquaporin Protein membrane channel through which water can diffuse. 97, 463, 674

arachnid Group of arthropods that contains spiders and scorpions. 395

arboreal Living in trees. 412

Archaea One of the three domains of life; contains prokaryotic cells that often live in extreme habitats and have unique genetic, biochemical, and physiological characteristics; its members are sometimes referred to as archaea. 14, 67, 297, 325

archaic human Regionally diverse descendants of *H. erectus* that lived in Africa, Asia, and Europe; considered by some to be a separate species. 421

archegonium Egg-producing structure, as in the moss life cycle. 355

Arctic tundra Biome that encircles the Earth just south of ice-covered polar seas in the Northern Hemisphere. 786

Ardi Fossilized remains of *Ardipithecus ramidus,* a hominin that lived 4.4 MYA. 416

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ardipithecine One of several species of *Ardipithecus,* a genus that contains humanlike hominins and lived some 4–5 MYA. 416

arteriole (ar-teer-ee-ohl) Vessel that takes blood from an artery to capillaries. 595

artery Vessel that takes blood away from the heart to arterioles; characteristically possesses thick, elastic, muscular walls. 592

arthropod Member of a phylum of invertebrates that contains, among other groups, crustaceans and insects that have an exoskeleton and jointed appendages. 394

articular cartilage (ar-tik-yuh-lur) Hyaline cartilaginous covering over the articulating surface of the bones of synovial joints. 576

artificial selection Change in the genetic structure of populations due to selective breeding by humans. 17, 252

ascus Fingerlike sac where ascospores are produced during sexual reproduction of sac fungi. 372

asexual reproduction Reproduction that requires only one parent and does not involve gametes. 160, 700

A site In a ribosome, the place where a tRNA carrying an amino acid is bound to mRNA. 200

associative learning Acquired ability to associate two stimuli or a stimulus and a response. 747

assortative mating Individuals tend to mate with those that have the same phenotype as themselves with respect to certain characteristics. 261

aster Short, radiating fibers about the centrioles at the poles of a spindle. 148

asthma (az-muh, as-) Condition in which bronchioles constrict and cause difficulty in breathing. 622, 660

atom Smallest particle of an element that displays the properties of the element. 9, 26

atomic mass Mass of an atom equal to the number of protons plus the number of neutrons within the nucleus. 27

atomic number Number of protons within the nucleus of an atom. 27

atomic symbol One or two letters that represent the name of an element—e.g., H stands for a hydrogen atom. 26

ATP synthase complex Complex formed of enzymes and their carrier proteins; functions in the production of ATP in chloroplasts and mitochondria. 110, 131

atrial natriuretic hormone (ANH) (ay-tree-ul nay-tree-yoo-ret-ik) Hormone secreted by the heart that increases sodium excretion and, therefore, lowers blood volume and pressure. 675

atrioventricular valve Valve located between the atrium and the ventricle. 592

atrium (ay-tree-um) One of the upper chambers of the heart, either the left atrium or the right atrium, that receives blood. 592

australopithecine One of several species of *Australopithecus*, a genus that contains the first generally recognized hominids. 418

Australopithecus africanus Hominid that lived between 3.6 and 3 MYA; e.g., Lucy, discovered at Hadar, Ethiopia, in 1974. 418

autoimmune disorder Disorder that results when the immune system mistakenly attacks the body's own tissues. 621

autonomic system (aw-tuh-nahm-ik) Branch of the peripheral nervous system that has control over the internal organs; consists of the sympathetic and parasympathetic divisions. 541

autoploidy Polyploid organism that contains a duplicated genome of the same species. 279

autosomal chromosome Any chromosome of a type that is the same in males and females of a species. 178

autosome (aw-tuh-sohm) Any chromosome other than the sex chromosomes. 144

autotroph Organism that can capture energy and synthesize organic nutrients from inorganic nutrients. 106, 770

auxins A group of plant hormones regulating growth, particularly cell elongation; most often indoleacetic acid (IAA). 470

avian influenza Flu caused by a virus that is able to spread from birds to humans. 313

axial skeleton (ak-see-ul) Portion of the skeleton that supports and protects the organs of the head, the neck, and the trunk. 572

axillary bud Bud located in the axil of a leaf. 432

axon (ak-sahn) Elongated portion of a neuron that conducts nerve impulses, typically from the cell body to the synapse. 527

B

Bacteria One of the three domains of life; contains prokaryotic cells that differ from archaea because they have their own unique genetic, biochemical, and physiological characteristics. 14, 67, 304

bacteriophage Virus that infects bacteria. 311

ball-and-socket joint The most freely movable type of joint (e.g., the shoulder or hip joint). 577

bark External part of a tree, containing cork, cork cambium, and phloem. 442

Barr body Dark-staining body (discovered by M. Barr) in the nuclei of female mammals that contains a condensed, inactive X chromosome. 214

basal body Cytoplasmic structure that is located at the base of and may organize cilia or flagella. 79

basal nuclei (bay-sul) Subcortical nuclei deep within the white matter that serve as relay stations for motor impulses and produce dopamine to help control skeletal muscle activities. 535

base Molecules tending to lower the hydrogen ion concentration in a solution and raise the pH numerically. 36

basement membrane Layer of nonliving material that anchors epithelial tissue to underlying connective tissue. 509

basidium Clublike structure in which nuclear fusion, meiosis, and basidiospore production occur during sexual reproduction of club fungi. 373

B cell Lymphocyte that matures in the bone marrow and, when stimulated by the presence of a specific antigen, gives rise to antibody-producing plasma cells. 601, 611

B cell receptor (BCR) Molecule on the surface of a B cell that binds to a specific antigen. 616

beneficial nutrient In plants, element that is either required or enhances the growth and production of a plant. 460

behavior Observable, coordinated responses to environmental stimuli. 744

bicarbonate ion Ion that participates in buffering the blood; the form in which carbon dioxide is transported in the bloodstream. 658

bilateral symmetry Body plan having two corresponding or complementary halves. 381

bile Secretion of the liver that is temporarily stored and concentrated in the gallbladder before being released into the small intestine, where it emulsifies fat. 634

binary fission Bacterial reproduction into two daughter cells without utilizing a mitotic spindle. 321

binge-eating disorder Condition characterized by overeating episodes that are not followed by purging. 644

biocultural evolution Phase of human evolution in which cultural events affect natural selection. 420

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biodiversity Variety of life within an ecosystem, biome, or biosphere. 800
biodiversity hotspot Region of the world that contains unusually large concentrations of species. 801
biogeochemical cycle (by-oh-jee-oh-kem-ih-kul) Circulating pathway of elements such as carbon and nitrogen involving exchange pools, storage areas, and biotic communities. 774
biogeography Study of the geographical distribution of organisms. 258
bioinformatics Computer technologies used to study the genome. 240
biological clock Internal mechanism that maintains a biological rhythm in the absence of environmental stimuli. 479
biological species concept The concept that defines species as groups of populations that have the potential to interbreed and are reproductively isolated from other groups. 272
biome One of the biosphere's major terrestrial communities, characterized by certain climatic conditions and particular types of plants. 785
biomolecules Organic molecules common to organisms: carbohydrates, proteins, fats, and nucleic acids. 44
biosphere (by-oh-sfeer) Zone of air, land, and water at the surface of the Earth in which living organisms are found. 12, 728
biotechnology Use of a natural biological system to produce a product or achieve an end desired by humans; may involve using recombinant DNA technology. 230
biotechnology product Product created by using biotechnology techniques. 233
biotic potential Maximum reproductive rate of an organism, given unlimited resources and ideal environmental conditions. 730
bipedalism Walking erect on two feet. 416
bird Endothermic vertebrate that has feathers and wings, is often adapted for flight, and lays hard-shelled eggs. 402
bivalve Type of mollusc with a shell composed of two valves; includes clams, oysters, and scallops. 391
blade Broad, expanded portion of a plant leaf that may be single or compound. 433
blastocoel Fluid-filled cavity of a blastula. 710
blastocyst (blas-tuh-sist) Early stage of human embryonic development that consists of a hollow, fluid-filled ball of cells. 716
blastopore Opening into the primitive gut formed at gastrulation. 711
blastula Hollow, fluid-filled ball of cells occurring during animal development prior to gastrula formation. 710
blind spot Region of the retina lacking rods or cones where the optic nerve leaves the eye. 554
blood pressure Force of blood pushing against the inside wall of an artery. 599
bone Connective tissue having protein fibers and a hard matrix of inorganic salts, notably calcium salts. 511
bottleneck effect Cause of genetic drift; occurs when a majority of genotypes are prevented from participating in the production of the next generation as a result of a natural disaster or human interference. 263
brain stem Portion of the brain consisting of the medulla oblongata, pons, and midbrain. 536
bronchi (sing., bronchus) Two major divisions of the trachea leading to the lungs. 654
bronchioles (brahng-kee-ohlz) Smaller air passages in the lungs that begin at the bronchi and terminate in alveoli. 654
brown algae Marine photosynthetic protists with a notable abundance of xanthophyll pigments; this group includes well-known seaweeds of northern rocky shores. 344
bryophyte Member of one of three phyla of nonvascular plants—the mosses, liverworts, and hornworts. 356
buffer Substance or group of substances that tends to resist pH changes of a solution, thus stabilizing its relative acidity and basicity. 37
bulbourethral gland (bul-boh-yoo-ree-thrul) Either of two small structures located below the prostate gland in males; each adds secretions to semen. 702
bulimia nervosa (byoo-lee-mee-uh, -lim-ee-, nur-voh-suh) Eating disorder characterized by binge eating followed by purging via self-induced vomiting or use of a laxative. 644
bulk feeder Animal that eats relatively large pieces of food. 628
bulk transport Movement of elements in an organism in large amounts. 98
bundle sheath Sheath located around the veins of a leaf; formed from tightly packed cells. 444
bursa (bur-suh) Saclike, fluid-filled structure, lined with synovial membrane, that occurs near a joint. 577

C

C_3 photosynthesis Type of photosynthesis in which the first stable product following carbon dioxide fixation is a 3-carbon compound produced by the Calvin cycle. 116
C_4 photosynthesis Type of photosynthesis in which the first stable product is a 4-carbon molecule that releases carbon dioxide to the Calvin cycle. 116
calcitonin (kal-sih-toh-nin) Hormone secreted by the thyroid gland that increases the blood calcium level. 689
Calorie (kcal) Amount of heat energy required to raise the temperature of 1 g of water 1°C. 34
Cambrian explosion Sudden appearance in the fossil record of most major groups of complex animals around 530 MYA. 381
camouflage Method of hiding from predators in which the organism's behavior, form, and pattern of coloration allow it to blend into the background and prevent detection. 763
CAM photosynthesis Crassulacean-acid metabolism; plant fixes carbon dioxide at night to produce a C_4 molecule that releases carbon dioxide to the Calvin cycle during the day. 117
capillary (kap-uh-lair-ee) Microscopic vessel connecting arterioles to venules; exchange of substances between blood and tissue fluid occurs across its thin walls. 595
capsid Protein coat or shell that surrounds a virion's nucleic acid. 310
capsule Gelatinous layer surrounding the cells of blue-green algae and certain bacteria. 67
carbaminohemoglobin Hemoglobin carrying carbon dioxide. 658
carbohydrate Class of organic compounds that includes monosaccharides, disaccharides, and polysaccharides. 639
carbonic anhydrase (kar-bahn-ik an-hy-drays, -drayz) Enzyme in red blood cells that speeds the formation of carbonic acid from the reactants water and carbon dioxide. 658
carcinogenesis (kar-suh-nuh-jen-uh-sis) Development of cancer. 153, 223
cardiac conduction system System of specialized cardiac muscle fibers that conduct impulses from the SA node to the chambers of the heart, causing them to contract. 594
cardiac cycle One complete cycle of systole and diastole for all heart chambers. 594
cardiac muscle Striated, involuntary muscle found only in the heart. 512
cardiac pacemaker Mass of specialized cardiac muscle tissue that controls the rhythm of the heartbeat; the SA node. 594
cardiovascular system Organ system in which blood vessels distribute blood under the pumping action of the heart. 517, 592

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carnivore (kar-nuh-vor) Consumer in a food chain that eats other animals. 770

carotenoid Yellow or orange pigment that serves as an accessory to chlorophyll in photosynthesis. 109

carotid body (kuh-raht-id) Structure located at the branching of the carotid arteries; contains chemoreceptors sensitive to the O_2, CO_2, and H^+ content in blood. 657

carpel Ovule-bearing unit that is a part of a pistil. 365, 491

carrier Heterozygous individual who has no apparent abnormality but can pass on an allele for a recessively inherited genetic disorder. 178

carrying capacity Maximum number of individuals of any species that can be supported by a particular ecosystem on a long-term basis. 732

cartilage Connective tissue in which the cells lie within lacunae separated by a flexible proteinaceous matrix. 511

Casparian strip Layer of impermeable lignin and suberin bordering four sides of root endodermal cells; prevents water and solute transport between adjacent cells. 463

catabolism Metabolic process that breaks down large molecules into smaller ones; catabolic metabolism. 135

cecum (see-kum) Small pouch that lies below the entrance of the small intestine and is the blind end of the large intestine. 630

cell Smallest unit that displays the properties of life; always contains cytoplasm surrounded by a plasma membrane. 9

cell body Portion of a neuron that contains a nucleus and from which dendrites and an axon extend. 527

cell cycle Repeating sequence of cellular events that consists of interphase, mitosis, and cytokinesis. 145

cell-mediated defense Specific mechanism of defense in which T cells destroy antigen-bearing cells. 616

cell plate Structure across a dividing plant cell that signals the location of new plasma membranes and cell walls. 150

cell suspension culture Plant tissue extraction of chemicals performed in a laboratory without needing to disturb plants in their natural environments. 500

cell theory One of the major theories of biology; states that all organisms are made up of cells and that cells come only from preexisting cells. 9, 64

cellular respiration Metabolic reactions that use the energy primarily from carbohydrates but also from fatty acid or amino acid breakdown to produce ATP molecules. 123

cellular slime mold Free-living amoeboid cells that feed on bacteria and yeasts by phagocytosis and aggregate to form a plasmodium that produces spores. 342

cellulose (sel-yuh-lohs, -lohz) Polysaccharide that is the major complex carbohydrate in plant cell walls. 48

cell wall Structure that surrounds a plant, protistan, fungal, or bacterial cell and maintains the cell's shape and rigidity. 67

central nervous system (CNS) Portion of the nervous system consisting of the brain and spinal cord. 526, 533

central vacuole In a plant cell, a large, fluid-filled sac that stores metabolites. During growth, it enlarges, forcing the primary cell wall to expand and the cell surface-area-to-volume ratio to increase. 74

centriole (sen-tree-ohl) Cellular structure, existing in pairs, that possibly organizes the mitotic spindle for chromosomal movement during mitosis and meiosis. 79

centromere (sen-truh-meer) Constriction where sister chromatids of a chromosome are held together. 144

centrosome Central microtubule organizing center of cells. In animal cells, it contains two centrioles. 78, 146

cephalization Having a well-recognized anterior head with a brain and sensory receptors. 382, 532

cephalopod Type of mollusc in which a modified foot develops into the head region; includes squid, cuttlefish, octopus, and nautilus. 391

cerebellum (ser-uh-bel-um) Part of the brain located posterior to the medulla oblongata and pons that coordinates skeletal muscles to produce smooth, graceful motions. 536

cerebral cortex (suh-ree-brul, ser-uh-brul kor-teks) Outer layer of cerebral hemispheres; receives sensory information and controls motor activities. 535

cerebral hemisphere One of the large, paired structures that together constitute the cerebrum of the brain. 535

cerebrospinal fluid Fluid found in the ventricles of the brain, in the central canal of the spinal cord, and in association with the meninges. 513, 534

cerebrum (sair-uh-brum, suh-ree-brum) Main part of the brain consisting of two large masses, or cerebral hemispheres; the largest part of the brain in mammals. 535

cervix (sur-viks) Narrow end of the uterus, which projects into the vagina. 704

cesarean section Birth by surgical incision of the abdomen and uterus. 719

character Any structural, chromosomal, or molecular feature that distinguishes one group from another. 296

character displacement Tendency for characteristics to be more divergent when similar species belong to the same community than when they are isolated from one another. 760

chemiosmosis Ability of certain membranes to use a hydrogen ion gradient to drive ATP formation. 113, 131

chemoreceptor (kee-moh-rih-sep-tur) Sensory receptor that is sensitive to chemical stimuli—for example, receptors for taste and smell. 550

chemosynthetic Organism able to synthesize organic molecules by using carbon dioxide as the carbon source and the oxidation of an inorganic substance (such as hydrogen sulfide) as the energy source. 323

chitin Strong but flexible nitrogenous polysaccharide found in the exoskeleton of arthropods. 48, 394

chlamydia infection (kluh-mid-ee-uh) Sexually transmitted disease, caused by the bacterium *Chlamydia trachomatis;* can lead to pelvic inflammatory disease. 708

chlorophyll, chlorophyll *a*, chlorophyll *b* Green pigment that absorbs solar energy and is important in algal and plant photosynthesis; occurs as chlorophyll *a* and chlorophyll *b*. 107, 109

chloroplast Membrane-bounded organelle in algae and plants with chlorophyll-containing membranous thylakoids; where photosynthesis takes place. 76, 107

cholesterol One of the major lipids found in animal plasma membranes; makes the membrane impermeable to many molecules. 93, 640

chordate Member of the phylum Chordata, which includes lancelets, tunicates, fishes, amphibians, reptiles, birds, and mammals; characterized by a notochord, dorsal tubular nerve cord, pharyngeal gill pouches, and a postanal tail at some point in the life cycle. 398

chorion (kor-ee-ahn) Extraembryonic membrane that contributes to placenta formation. 715

chorionic villi (kor-ee-ahn-ik vil-eye) Treelike extensions of the chorion that project into the maternal tissues at the placenta. 717

chorionic villi sampling (CVS) Removal of cells from the chorionic villi portion of the placenta. Karyotyping is done to

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determine if the fetus has a chromosomal abnormality. 181

choroid (kor-oyd) Vascular, pigmented middle layer of the eyeball. 554

chromatin (kroh-muh-tin) Network of fine threads in the nucleus that are composed of DNA and proteins. 70, 214

chromatin remodeling complex During transcription, a protein complex that moves aside nucleosomes so that mRNA polymerase and transcription factors have access to and can start transcription of a gene. 215

chromosome (kroh-muh-som) Chromatin condensed into a compact structure. 70

chronic bronchitis Obstructive pulmonary disorder that tends to recur; marked by inflamed airways filled with mucus and degenerative changes in the bronchi, including loss of cilia. 660

chyme Thick, semiliquid food material that passes from the stomach to the small intestine. 634

ciliary body (sil-ee-air-ee) Structure associated with the choroid layer that contains ciliary muscle and controls the shape of the lens of the eye. 554

ciliary muscle Within the ciliary body of the vertebrate eye, the ciliary muscle controls the shape of the lens. 555

ciliate Complex unicellular protist that moves by means of cilia and digests food in food vacuoles. 340

cilium (pl., cilia) (sil-ee-um) Short, hairlike projection from the plasma membrane, occurring usually in large numbers. 79

circadian rhythm Regular physiological or behavioral event that occurs on an approximately 24-hour cycle. 479, 693

clade Taxon or other group consisting of an ancestral species and all of its descendants, forming a distinct branch on a phylogenetic tree. 300

cladistics Method of systematics that uses shared derived characters to place organisms in clades and construct cladograms. 300

cladogram In cladistics, a branching diagram that shows the relationship among species in regard to their shared derived characters. 300

class One of the categories, or taxa, used by taxonomists to group species; class is the taxon above the order level. 14, 296

classical conditioning Type of learning whereby an unconditioned stimulus that elicits a specific response is paired with a neutral stimulus so that the response becomes conditioned. 747

cleavage Cell division without cytoplasmic addition or enlargement; occurs during the first stage of animal development. 710

cleavage furrow In animal cells, an indentation that encircles the cell to divide the cytoplasm during cytokinesis. 150

climate Weather condition of an area, including especially prevailing temperature and average/yearly rainfall. 782

climax community In ecology, community that results when succession has come to an end. 767

clitoris Small, erectile, female organ located in the vulva; homologous to the penis. 704

cloaca Posterior portion of the digestive tract in certain vertebrates that receives feces and urogenital products. 630

clonal selection model Concept that an antigen selects which lymphocyte will undergo clonal expansion and produce more lymphocytes bearing the same type of antigen receptor. 617

closed circulatory system Blood is confined to vessels and is kept separate from the interstitial fluid. 590

cnidarian Invertebrate in the phylum Cnidaria existing as either a polyp or a medusa with two tissue layers and radial symmetry. 386

coal Fossil fuel formed millions of years ago from plant material that did not decay. 364

cochlea (kohk-lee-uh, koh-klee-uh) Portion of the inner ear that resembles a snail's shell and contains the spiral organ, the sense organ for hearing. 559

codominance Inheritance pattern in which both alleles of a gene are equally expressed. 182

codon Three-base sequence in messenger RNA that causes the insertion of a particular amino acid into a protein or termination of translation. 198

coelom (see-lum) Embryonic body cavity lying between the digestive tract and body wall that becomes the thoracic and abdominal cavities. 383

coelomate Animal having a coelom. 390

coenzyme (koh-en-zym) Nonprotein organic molecule that aids the action of the enzyme to which it is loosely bound. 91

coevolve (coevolution) Interaction of two species such that each influences the evolution of the other. 495

cofactor Nonprotein adjunct required by an enzyme in order to function; many cofactors are metal ions, others are coenzymes. 91

cohesion Clinging together of water molecules. 33

cohesion-tension model Explanation for upward transport of water in xylem, based upon transpiration-created tension and the cohesive properties of water molecules. 454

cohort Group of individuals having a statistical factor in common, such as year of birth, in a population study. 730

coleoptile Protective sheath that covers the young leaves of a seedling. 471

collecting duct Duct within the kidney that receives fluid from several nephrons; the reabsorption of water occurs here. 671

collenchyma cell Plant tissue composed of cells with unevenly thickened walls; supports growth of stems and petioles. 436

colon (koh-lun) The major portion of the large intestine, consisting of the ascending colon, the transverse colon, and the descending colon. 636

colonial flagellate hypthesis The proposal first put forth by Haeckel that protozoans descended from colonial protists; supported by the similarity of sponges to flagellated protists. 381

colony Loose association of cells that remain independent for most functions. 346

columnar epithelium Type of epithelial tissue with cylindrical cells. 509

commensalism Symbiotic relationship in which one species is benefited, and the other is neither harmed nor benefited. 764

common ancestor Ancestor held in common by at least two lines of descent. 13, 256, 298

communication Signal by a sender that influences the behavior of a receiver. 752

community Assemblage of populations interacting with one another within the same environment. 12, 728, 760

compact bone Type of bone that contains osteons consisting of concentric layers of matrix and osteocytes in lacunae. 511, 576

companion cell Cell associated with sieve-tube members in the phloem of vascular plants. 437, 452

comparative genomics Study of genomes through a comparison of their coding and noncoding DNA sequences. 221

competition Interaction between two organisms in which both require the same limited resource, which results in harm to both. 760

competitive exclusion principle Theory that no two species can occupy the same niche. 760

competitive inhibition Form of enzyme inhibition whereby the substrate and inhibitor are both able to bind to the enzyme's active site; each complexes with the enzyme. Only when the substrate is at the active site will product form. 92

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complement Collective name for a series of enzymes and activators in the blood, some of which may bind to antibody and may lead to rupture of a foreign cell. 612

complementary base pairing Hydrogen bonding between particular bases. In DNA, thymine (T) pairs with adenine (A), and guanine (G) pairs with cytosine (C); in RNA, uracil (U) pairs with A, and G pairs with C. 57, 194

complex carbohydrates Mixture of carbohydrates that must be digested to release sugars; preferably also contain cellulose that acts as roughage in the diet. 48

compound Substance having two or more different elements, united chemically in fixed ratio. 29

compound light microscope Consists of a two-lens system, one above the other, to magnify an object. 66

concentration gradient Amount that changes from high to low or vice versa. 96

conclusion Statement following an experiment as to whether the results support the hypothesis. 5

conifer Member of a group of cone-bearing gymnosperm plants that includes pine, cedar, and spruce trees. 362

conjugation Transfer of genetic materials from one cell to another. 322, 345

conjunctiva Delicate membrane that lines the eyelid protecting the sclera. 554

connective tissue Type of tissue characterized by cells separated by a matrix that often contains fibers. 510

conservation biology Scientific discipline that seeks to understand the effects of human activities on species, communities, and ecosystems and to develop practical approaches to preventing the extinction of species and the destruction of ecosystems. 800

consumer Organism that feeds on another organism in a food chain; primary consumers eat plants, and secondary consumers eat animals. 770

control group Sample that goes through all the steps of an experiment but lacks the factor or is not exposed to the factor being tested; used as a standard against which experimental results are checked. 5

copulation Sexual union between a male and a female. 700

coral reef Area of biological abundance in warm, shallow tropical waters on and around coral formations. 793

cork cambium Lateral meristem that produces cork. 442

corm Underground, upright plant stem where food is stored, usually in the form of starch. 499

cornea (kor-nee-uh) Transparent, anterior portion of the outer layer of the eyeball. 554

corpus luteum (kor-pus loot-ee-um) Yellow body that forms in the ovary from a follicle that has discharged its secondary oocyte; secretes progesterone and some estrogen. 705

cortex In plants, ground tissue bounded by the epidermis and vascular tissue in stems and roots; in animals, outer layer of an organ such as the cortex of the kidney or the adrenal gland. 438

cortisol (kor-tuh-sawl) Glucocorticoid secreted by the adrenal cortex that responds to stress on a long-term basis; reduces inflammation and promotes protein and fat metabolism. 690

cotyledon Seed leaf for the embryo of a flowering plant; provides nutrient molecules for the developing plant before photosynthesis begins. 365, 496

countercurrent flow mechanism Fluids flow side-by-side in opposite directions, as in the exchange of fluids in the kidneys. 473, 652

coupled reaction Reaction that occurs simultaneously; one is an exergonic reaction that releases energy, and the other is an endergonic reaction that requires energy in order to occur. 89

covalent bond (coh-vay-lent) Chemical bond in which atoms share one pair of electrons. 31

cranial nerve Nerve that arises from the brain. 539

cristae Short, fingerlike projections formed by the folding of the inner membrane of mitochondria. 128

Cro-Magnon Common name for the first fossils to be designated *Homo sapiens*. 422

crop Part of the digestive tract in birds and some invertebrates that stores or digests food. 630

crossing-over Exchange of segments between nonsister chromatids of a tetrad during meiosis. 156

crustacean Member of a group of marine arthropods that contains, among others, shrimps, crabs, crayfish, and lobsters 395

cuboidal epithelium Type of epithelial tissue with cube-shaped cells. 509

culture Total pattern of human behavior; includes technology and the arts and is dependent upon the capacity to speak and transmit knowledge. 420

Cushing syndrome (koosh-ing) Condition resulting from hypersecretion of glucocorticoids; characterized by thin arms and legs and a "moon face," and accompanied by high blood glucose and sodium levels. 691

cuticle Waxy layer covering the epidermis of a plant that protects the plant against water loss and disease-causing organisms. 355, 436

cyanobacteria Photosynthetic bacteria that contain chlorophyll and release oxygen; formerly called blue-green algae. 324

cyanogenic glycoside Plant compound that contains sugar; produces cyanide. 482

cycad Type of gymnosperm with palmate leaves and massive cones; cycads are most often found in the tropics and subtropics. 362

cyclic adenosine monophosphate (cAMP) (sy-klik, sih-klik) ATP-related compound that acts as the second messenger in peptide hormone transduction; it initiates activity of the metabolic machinery. 684

cytochrome Any of several iron-containing protein molecules that serve as electron carriers in photosynthesis and cellular respiration. 130

cytokine (sy-tuh-kyn) Type of protein secreted by a T lymphocyte that stimulates cells of the immune system to perform their various functions. 473, 613

cytokinesis (sy-tuh-kyn-ee-sus) Division of the cytoplasm following mitosis and meiosis. 145

cytokinin Plant hormone that promotes cell division; often works in combination with auxin during organ development in plant embryos. 473

cytoplasm (sy-tuh-plaz-um) Contents of a cell between the nucleus and the plasma membrane that contains the organelles. 67

cytoskeleton Internal framework of the cell, consisting of microtubules, actin filaments, and intermediate filaments. 78

cytotoxic T cell (sy-tuh-tahk-sik) T lymphocyte that attacks and kills antigen-bearing cells. 616

D

data Facts or pieces of information collected through observation and/or experimentation. 5

daughter cell Cell that arises from a parental cell by mitosis or meiosis. 146

day-neutral plant Plant whose flowering is not dependent on day length, e.g., tomato and cucumber. 481

deamination Removal of an amino group ($–NH_2$) from an amino acid or other organic compound. 135

deciduous Plant that sheds its leaves annually. 433

decomposer Organism, usually a bacterium or fungus, that breaks down organic matter into inorganic nutrients that can be recycled in the environment. 770

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dehiscent Anther, fruit, or other plant structure that opens to permit the release of reproductive bodies inside. 497

dehydration reaction Chemical reaction resulting in a covalent bond and the loss of a water molecule. 46

delayed allergic response Allergic response initiated at the site of the allergen by sensitized T cells, involving macrophages and regulated by cytokines. 622

deletion Change in chromosome structure in which the end of a chromosome breaks off or two simultaneous breaks lead to the loss of an internal segment; often causes abnormalities (e.g., cri du chat syndrome). 164

demographic transition Due to industrialization, a decline in the birthrate following a reduction in the death rate so that the population growth rate is lowered. 737

denatured (denaturation) Loss of an enzyme's normal shape so that it no longer functions; caused by a less than optimal pH or temperature. 91

dendrite (den-dryt) Branched ending of a neuron that conducts signals toward the cell body. 527

dendritic cell Antigen-presenting cell of the epidermis and mucous membranes. 613

denitrification Conversion of nitrate or nitrite to nitrogen gas by bacteria in soil. 775

dense fibrous connective tissue Type of connective tissue containing many collagen fibers packed together and found in tendons and ligaments, for example. 511

density-dependent factor Biotic factor, such as disease or competition, that affects population size according to the population's density. 734

density-independent factor Abiotic factor, such as fire or flood, that affects population size independent of the population's density. 733

dental caries (kar-eez) Tooth decay that occurs when bacteria within the mouth metabolize sugar and give off acids that erode teeth; a cavity. 633

deoxyribose Pentose sugar found in DNA that has one less hydroxyl group than ribose. 47

depolarization Loss in polarization, as when a nerve impulse occurs. 528

derived character Structural, physiological, or behavioral trait that is present in a specific lineage and is not present in the common ancestor for several lineages. 298

dermis Region of skin that lies beneath the epidermis. 515

desert Ecological biome characterized by a limited amount of rainfall; deserts have hot days and cool nights. 789

detrital food web (dih-tryt-ul) Complex pattern of interlocking and crisscrossing food chains that begins with detritus. 773

detritus Partially decomposed organic matter derived from tissues and animal wastes. 770

deuterostomes Group of coelomate animals in which the second embryonic opening is associated with the mouth; the first embryonic opening, the blastopore, is associated with the anus. 383

diaphragm (dy-uh-fram) Dome-shaped horizontal sheet of muscle and connective tissue that divides the thoracic cavity from the abdominal cavity. 707

diastole (dy-as-tuh-lee) Relaxation period of a heart chamber during the cardiac cycle. 594

diastolic pressure (dy-uh-stahl-ik) Arterial blood pressure during the diastolic phase of the cardiac cycle. 599

diatom Golden-brown alga with a cell wall having two parts, or valves; significant part of phytoplankton. 343

diencephalon (dy-en-sef-uh-lahn) Portion of the brain in the region of the third ventricle that includes the thalamus and hypothalamus. 536

differentially permeable Ability of plasma membranes to regulate the passage of substances into and out of the cell, allowing some to pass through and preventing the passage of others. 96

digestive system Organ system that includes the mouth, esophagus, stomach, small intestine, and large intestine (colon), which receives food and digests it into nutrient molecules. Also has associated organs: teeth, tongue, salivary glands, liver, gallbladder, and pancreas. 517

dihybrid cross Single genetic cross involving two different traits, such as flower color and plant height. 174

dinoflagellate Photosynthetic unicellular protist with two flagella, one whiplash and the other located within a groove between protective cellulose plates; a significant part of phytoplankton. 343

diploid life cycle Presence of two of each type of chromosome at interphase of the cell cycle. 160

diploid (2n) number Cell condition in which two of each type of chromosome are present in the nucleus. 146

directional selection Outcome of natural selection in which an extreme phenotype is favored, usually in a changing environment. 265

disaccharide (dy-sak-uh-ryd) Sugar that contains two units of a monosaccharide (e.g., maltose). 47

disruptive selection Outcome of natural selection in which the two extreme phenotypes are favored over the average phenotype, leading to more than one distinct form. 265

distal convoluted tubule Final portion of a nephron that joins with a collecting duct; associated with tubular secretion. 671

DNA (deoxyribonucleic acid) Nucleic acid polymer produced from covalent bonding of nucleotide monomers that contain the sugar deoxyribose; the genetic material of nearly all organisms. 10, 56, 192

DNA fingerprinting The use of DNA fragment lengths resulting from restriction enzyme cleavage to identify particular individuals. 197

DNA ligase (ly-gays) Enzyme that links DNA fragments; used during production of recombinant DNA to join foreign DNA to vector DNA. 232

DNA microarrays Thousands of different DNA fragments (probes) arranged in an array (grid); used to detect and measure gene expression. 240

DNA polymerase During replication, an enzyme that joins the nucleotides complementary to a DNA template. 196

DNA replication Synthesis of a new DNA double helix prior to mitosis and meiosis in eukaryotic cells and during prokaryotic fission in prokaryotic cells. 196

domain The primary taxonomic group above the kingdom level; all living organisms may be placed in one of three domains. 14, 296

dominant allele (uh-leel) Allele that exerts its phenotypic effect in the heterozygote; it masks the expression of the recessive allele. 173

dormancy In plants, a cessation of growth under conditions that seem appropriate for growth. 472

dorsal root ganglion (gang-glee-un) Mass of sensory neuron cell bodies located in the dorsal root of a spinal nerve. 539, 540

double fertilization In flowering plants, one sperm joins with polar nuclei within the embryo sac to produce a 3n endosperm nucleus, and another sperm joins with an egg to produce a zygote. 367, 495

double helix Double spiral; describes the three-dimensional shape of DNA. 194
doubling time Number of years it takes for a population to double in size. 737
drug abuse Compulsive and self-damaging use of a drug that primarily affects the nervous system. 542
dryopithecine Tree dweller; ancestral to apes. 415
duodenum (doo-uh-dee-num) First part of the small intestine where chyme enters from the stomach. 634
duplication Change in chromosome structure in which a particular segment is present more than once in the same chromosome. 164

E

Ebola One of a number of different viruses; causes a deadly hemorrhagic fever. 313
ecdysozoa Protostome characterized by periodic molting of the exoskeleton. Includes the roundworms and the arthropods. 383
echinoderm Phylum of marine animals that includes sea stars, sea urchins, and sand dollars; characterized by radial symmetry and a water vascular system. 397
ecological niche Role an organism plays in its community, including its habitat and its interactions with other organisms. 760
ecological pyramid Pictorial graph based on the biomass, number of organisms, or energy content of various trophic levels in a food web—from the producer to the final consumer populations. 773
ecology Study of the interactions of organisms with other organisms and with the physical and chemical environment. 728, 770
ecosystem (ek-oh-sis-tum, ee-koh-) Biological community together with the associated abiotic environment; characterized by energy flow and chemical cycling. 12, 728
ecosystem diversity Variety of species in a particular locale, dependent on the species interactions. 801
ectoderm Outermost primary tissue layer of an animal embryo; gives rise to the nervous system and the outer layer of the integument. 711
ectotherm Organism having a body temperature that varies according to the environmental temperature. 402
electrocardiogram (ECG) (ih-lek-troh-kar-dee-uh-gram) Recording of the electrical activity associated with the heartbeat. 594
electromagnetic receptor Sensory receptor that detects energy of different wavelengths, such as electricity, magnetism, and light. 550
electron Negative subatomic particle, moving in an energy level around the nucleus of an atom. 27
electronegativity Ability of an atom to attract electrons toward itself in a chemical bond. 32
electron shell Concentric energy levels in which electrons orbit. 27
electron transport chain (ETC) Passage of electrons along a series of membrane-bounded carrier molecules from a higher to lower energy level; the energy released is used for the synthesis of ATP. 110, 125, 130
element Substance that cannot be broken down into substances with different properties; composed of only one type of atom. 26
El Nino—Southern Oscillation Warming of water in the Eastern Pacific equatorial region such that the Humboldt Current is displaced with possible negative results, including reduction in marine life. 784
elongation During DNA replication or the formation of mRNA during transcription, elongation is the step whereby the bases are added to the new or “daughter” strands of DNA or the mRNA transcript strand is lengthened, respectively. 202
embryonic development Period of development from the second through eighth weeks. 715
embryonic disk Stage of embryonic development following the blastocyst stage that has two layers; one layer will be endoderm, and the other will be ectoderm. 717
embryophyta Land plants that produce embryos protected from drying out. 353
embryo sac Female gametophyte of flowering plants that produces an egg cell. 366, 490
emphysema (em-fih-see-muh) Degenerative lung disorder in which the bursting of alveolar walls reduces the total surface area for gas exchange. 660
endangered species A species that is in peril of immediate extinction throughout all or most of its range (e.g., California condor, snow leopard). 800
endergonic reaction Chemical reaction that requires an input of energy; opposite of exergonic reaction. 88
endocrine system Organ system involved in the coordination of body activities; uses hormones as chemical signals secreted into the bloodstream. 516, 682
endocytosis Process by which substances are moved into the cell from the environment by phagocytosis (cellular eating) or pinocytosis (cellular drinking); includes receptor-mediated endocytosis. 98
endoderm Innermost primary tissue layer of an animal embryo that gives rise to the linings of the digestive tract and associated structures. 711
endodermis Plant root tissue that forms a boundary between the cortex and the vascular cylinder. 438
endomembrane system A collection of membranous structures involved in transport within the cell. 75
endometrium Mucous membrane lining the interior surface of the uterus. 704
endoplasmic reticulum (ER) (en-duh-plaz-mik reh-tik-yuh-lum) System of membranous saccules and channels in the cytoplasm, often with attached ribosomes. 71
endoskeleton Protective internal skeleton, as in vertebrates. 571
endosperm In angiosperms, the 3n tissue that nourishes the embryo and seedling and is formed as a result of a sperm joining with two polar nuclei. 495
endospore Spore formed within a cell; certain bacteria form endospores. 321
endosymbiotic theory Possible explanation of the evolution of eukaryotic organelles by phagocytosis of prokaryotes. 334
endotherm Animal that maintains a constant body temperature independent of the environmental temperature. 403
energy Capacity to do work and bring about change; occurs in a variety of forms. 9, 86
energy of activation Energy that must be added in order for molecules to react with one another. 90
enhancer DNA sequence that increases the level of transcription when a transcription activator binds to it. 213
entropy Measure of disorder or randomness. 87
enzyme (en-zym) Organic catalyst, usually a protein, that speeds a reaction in cells due to its particular shape. 46, 90
eosinophil (ee-oh-sin-oh-fill) White blood cell containing cytoplasmic granules that stain with acidic dye. 613
epidermal tissue Exterior tissue, usually one cell thick, of leaves, young stems, roots, and other parts of plants. 436
epidermis In plants, tissue that covers roots, leaves, and stems of a nonwoody organism; in animals, the outer protective region of the skin. 436, 515
epididymis (ep-uh-did-uh-mus) Coiled tubule next to the testes where sperm

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mature and may be stored for a short time. 702

epiglottis (ep-uh-glaht-us) Structure that covers the glottis during the process of swallowing. 633, 654

epinephrine (ep-uh-nef-rin) Hormone secreted by the adrenal medulla in times of stress; adrenaline. 690

epiphyte Plant that takes its nourishment from the air because its placement among other plants gives it an aerial position. 790

episiotomy (ih-pee-zee-aht-uh-mee) Surgical procedure performed during childbirth in which the opening of the vagina is enlarged to avoid tearing. 720

epithelial tissue Type of tissue that lines hollow organs and covers surfaces; epithelium. 508

equilibrium population Population whose members exhibit logistic population growth and whose size remains at or near the carrying capacity. Its members are large in size, slow to mature, have a long life span, have few offspring, and provide much care to offspring (e.g., bears, lions). 735

erection Increase in blood flow to the penis during sexual arousal, causing the penis to stiffen and become erect. 702

E site In a ribosome, the place where a spent tRNA exits the ribosome. 200

esophagus (ih-sahf-uh-gus) Muscular tube for moving swallowed food from the pharynx to the stomach. 633

essential nutrient In plants, substance required for normal growth, development, or reproduction. 460

estrogen (es-truh-jun) Female sex hormone that helps maintain sex organs and secondary sex characteristics. 705

estuary Portion of the ocean located where a river enters and fresh water mixes with salt water. 792

ethylene Plant hormone that causes ripening of fruit and is also involved in abscission. 475

euchromatin Chromatin that is extended and accessible for transcription. 214

eudicot Abbreviation of eudicotyledon. Flowering plant group; members have two embryonic leaves (cotyledons), net-veined leaves, vascular bundles in a ring, flower parts in fours or fives and their multiples, and other characteristics. 365, 434

Eudicotyledones Class of flowering plants, characterized by two embryonic leaves (cotyledons), net-veined leaves, vascular bundles in a ring, flower parts in fours or fives and their multiples, and other characteristics. 365

euglenoid Flagellated and flexible freshwater unicellular protist that usually contains chloroplasts and has a semirigid cell wall. 338

Eukarya One of the three domains of life, consisting of organisms with eukaryotic cells and further classified into the kingdoms Protista, Fungi, Plantae, and Animalia. 14, 68

eukaryotic cell (eukaryote) Type of cell that has a membrane-bounded nucleus and membranous organelles. 14, 68, 304

eutrophication Enrichment of water by inorganic nutrients used by phytoplankton. Often, overenrichment caused by human activities leads to excessive bacterial growth and oxygen depletion. 775, 791

eutrophic lake Lake containing many nutrients and decaying organisms, often tinted green with algae. 791

evolution Descent of organisms from common ancestors with the development of genetic and phenotypic changes over time that make them more suited to the environment. 253

evolutionary tree Diagram that shows how groups of organisms are related by way of common ancestors. 13, 298

evolutionary species concept Every species has its own evolutionary history, which is partly documented in the fossil record. 272

excretion Elimination of metabolic wastes by an organism at exchange boundaries such as the plasma membrane of unicellular organisms and excretory tubules of multicellular animals. 666

exergonic reaction Chemical reaction that releases energy; opposite of endergonic reaction. 88

exocytosis Process in which an intracellular vesicle fuses with the plasma membrane so that the vesicle's contents are released outside the cell. 98

exon A segment of a gene that codes for a protein. 199

exophthalmic goiter (ex-op-thowl-mick goi-tur) Enlargement of the thyroid gland accompanied by an abnormal protrusion of the eyes. 689

exoskeleton Protective external skeleton, as in arthropods. 570

experiment Test of an experimental variable for the purpose of collecting data. 5

experimental variable A value that is expected to change as a result of an experiment; represents the factor being tested by the experiment. 5

expiration (ek-spuh-ray-shun) Act of expelling air from the lungs; also called exhalation. 656

exponential growth Growth at a constant rate of increase per unit of time; can be expressed as a constant fraction or exponent. 732

external respiration Exchange of oxygen and carbon dioxide between alveoli and blood. 650

extinction Total disappearance of a species or higher group. 292, 735, 800

extracellular matrix (ECM) Materials secreted by animal cells that form a complex network which supports the cells and allows them to communicate. 99

extraembryonic membrane (ek-struh-em-bree-ahn-ik) Membrane that is not a part of the embryo but is necessary to the continued existence and health of the embryo. 700, 715

F

F_1 generation In genetics, the first (filial) generation of offspring. 172

F_2 generation In genetics, the second (filial) generation of offspring. 172

facilitated diffusion Passive transfer of a substance into or out of a cell along a concentration gradient by a process that requires a carrier. 96

facultative anaerobe Prokaryote that is able to grow in either the presence or the absence of gaseous oxygen. 323

FAD Flavin adenine dinucleotide; a coenzyme of oxidation-reduction that becomes $FADH_2$ as oxidation of substrates occurs, and then delivers electrons to the electron transport chain in mitochondria during cellular respiration. 124

family One of the categories, or taxa, used by taxonomists to group species; the taxon above the genus level. 14, 296

fat Organic molecule that contains glycerol and fatty acids and is found in adipose tissue. 49, 640

fatty acid Molecule that contains a hydrocarbon chain and ends with an acid group. 49

female gametophyte In seed plants, the gametophyte that produces an egg; in flowering plants, an embryo sac. 363, 490

fermentation Anaerobic breakdown of glucose that results in a gain of two ATP and end products such as alcohol and lactate. 125, 133

fern Member of a group of plants that have large fronds; in the sexual life cycle, the independent gametophyte produces flagellated sperm, and the vascular sporophyte produces windblown spores. 360

fertilization Union of a sperm nucleus and an egg nucleus, which creates a zygote. 155, 705

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fetal development Period of development from the ninth week through birth. 718
fiber Structure resembling a thread; also, plant material that is undigestible. 639
fibrin Insoluble protein threads formed from fibrinogen during blood clotting. 603
fibroblast Cell in connective tissues that produces fibers and other substances. 510
filament End-to-end chains of cells that form as cell division occurs in only one plane; in plants, the elongated stalk of a stamen. 345
filter feeder Method of obtaining nourishment by certain animals that strain minute organic particles from the water in a way that deposits them in the digestive tract. 385, 628
fimbria (pl., fimbriae) (fim-bree-uh) Fingerlike extension from the oviduct near the ovary. 704
first messenger Chemical signal such as a peptide hormone that binds to a plasma membrane receptor protein and alters a cell's metabolism because a second messenger is activated. 684
fitness Ability of an organism to reproduce and pass its genes to the next fertile generation; measured against the ability of other organisms to reproduce in the same environment. 748
fixed action pattern (FAP) Innate behavior pattern that is stereotyped, spontaneous, independent of immediate control, genetically encoded, and independent of individual learning. 746
flagellum (pl., flagella) (fluh-jel-um) Slender long extension that propels a cell through a fluid medium. 79, 383
flame cell Found along excretory tubules of planarians; functions in propelling fluid through the excretory canals and out of the body. 387, 667
flatworm Unsegmented worm lacking a body cavity; phylum Platyhelminthes. 387
fluid feeder Animal that gains needed nutrients by sucking nutrient-rich fluids from another living organism. 628
fluid-mosaic model Model for the plasma membrane based on the changing location and pattern of protein molecules in a fluid phospholipid bilayer. 93
follicle (fahl-ih-kul) Structure in the ovary that produces a secondary oocyte and the hormones estrogen and progesterone. 705
follicle-stimulating hormone (FSH) Hormone secreted by the anterior pituitary gland that stimulates the development of an ovarian follicle in a female or the production of sperm in a male. 703
follicular phase First half of the ovarian cycle, during which the follicle matures and much estrogen (and some progesterone) is produced. 706
fontanel (fahn-tun-el) Membranous region located between certain cranial bones in the skull of a fetus or infant. 572, 718
food chain The order in which one population feeds on another in an ecosystem, from detritus (detrital food chain) or producer (grazing food chain) to final consumer. 773
food web In ecosystems, complex pattern of interlocking and crisscrossing food chains. 772
foraging behavior Manner in which an animal finds and eats food. 748
foramen magnum (fuh-ray-mun mag-num) Opening in the occipital bone of the vertebrate skull through which the spinal cord passes. 572
foraminiferan Member of the phylum Foraminifera bearing a calcium carbonate test with many openings through which pseudopods extend. 339
foreign antigen Organism does not produce this type of antigen. 615
foreskin Skin covering the glans penis in uncircumcised males. 702
formed element Constituent of blood that is either cellular (red blood cells and white blood cells) or at least cellular in origin (platelets). 600
fossil Evidence of usually an extinct species that has been preserved in the Earth's crust. 255
fossil record History of life recorded from remains from the past. 255
founder effect Cause of genetic drift due to colonization by a limited number of individuals who, by chance, have different gene frequencies than the parent population. 263
fovea centralis Region of the retina consisting of densely packed cones; responsible for the greatest visual acuity. 554
frameshift mutation Alteration in a gene due to deletion of a base, so that the reading "frame" is shifted; can result in a nonfunctional protein. 204
frond Leaf of a fern. 360
fruit Flowering plant structure consisting of one or more ripened ovaries that usually contain seeds. 367, 490, 497
functional genomics Study of DNA function at the genomic level; involves the study of many genes simultaneously and the use of microarrays. 240
functional group Specific cluster of atoms attached to the carbon skeleton of organic molecules that enters into reactions and behaves in a predictable way. 45
fungus (pl., fungi) Saprotrophic decomposer; the body is made up of filaments called hyphae that form a mass called a mycelium. 370

G

G_0 stage In the cell cycle, a period of time that occurs should a cell leave the cycle during the G_1 stage before committing to the complete cycle. 145
G_1 stage In the cell cycle, a period of time during which the cell grows in size; includes the G_1 checkpoint when cells commit to completing the cycle. 145
G_2 stage In the cell cycle, a period of time after the S stage and before the M stage during which growth includes organelle duplication. 145
G3P In photosynthesis, a Krebs cycle molecule that is the starting point for many types of organic molecules produced by plants, including glucose and starch. In cellular respiration, the molecule that occurs after glucose is split during glycolysis. 114, 126
gallbladder Organ attached to the liver that stores and concentrates bile. 638
gamete (ga-meet, guh-meet) Haploid sex cell; the egg or a sperm, which join in fertilization to form a zygote. 155, 709
gametophyte Haploid generation of the alternation of generations life cycle of a plant; produces gametes that unite to form a diploid zygote. 354
ganglion Collection or bundle of neuron cell bodies usually outside the central nervous system. 532, 540
gap junction Junction between animal cells that provides a passageway for intercellular transport. 99
gastropod Mollusc with a broad flat foot for crawling (e.g., snails and slugs). 391
gastrovascular cavity In animals with an incomplete digestive tract, a cavity that serves for digestion of food and transport of oxygen and nutrients to body cells. 386
gastrulation Stage of animal development during which germ layers form, at least in part, by invagination. 711
gene Unit of heredity existing as alleles on the chromosomes; in diploid organisms, typically two alleles are inherited—one from each parent. 10, 57, 199
gene cloning Production of one or more copies of the same gene. 232
gene flow Sharing of genes between two populations through interbreeding. 261
gene locus Specific location of a particular gene on homologous chromosomes. 173
gene pharming Use of a transgenic organism to produce a commercial medical product. 236

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gene pool Total of all the genes of all the individuals in a population. 200, 260

gene theory Concept that organisms contain coded information dictating their form, function, and behavior. 10

gene therapy Correction of a detrimental mutation by the addition of normal DNA and its insertion into a genome. 237

genetically engineered Alteration of genomes for medical or industrial purposes. 232

genetically modified organism (GMO) Organism that carries the genes of another organism as a result of DNA technology. 232

genetic code Universal code that has existed for eons; specifies protein synthesis in the cells of all living things. Each codon consists of three letters standing for the DNA nucleotides that make up one of the 20 amino acids found in proteins. 198

genetic diversity Variety among members of a population. 800

genetic drift Mechanism of evolution due to random changes in the allelic frequencies of a population; more likely to occur in small populations or when only a few individuals of a large population reproduce. 263

genetic mutation Alteration in chromosome structure or number and also an alteration in a gene due to a change in DNA composition. 58, 204

genetic profile Gene expression in an individual or a cell as detected by the use of a microarray. 240

genome Full set of genetic information for a species or a virus. 57, 238

genotype (jee-nuh-typ) Genes of an individual for a particular trait or traits; often designated by letters, for example, *BB* or *Aa.* 173

genus One of the categories, or taxa, used by taxonomists to group species; contains those species that are most closely related through evolution. 14, 296

germinate Beginning of growth of a seed, spore, or zygote, especially after a period of dormancy. 498

germ layer Primary tissue layer of a vertebrate embryo—namely, ectoderm, mesoderm, or endoderm. 383, 711

geologic timescale History of the Earth since the beginning time divided into eras, periods, and epochs based in part on the fossil record. 292

gibberellin Plant hormone promoting increased stem growth; also involved in flowering and seed germination. 472

gills Respiratory organ in most aquatic animals; in fish, an outward extension of the pharynx. 593, 651

ginkgo Member of phylum Ginkgophyta; maidenhair tree. 362

gizzard Muscular part of the digestive tract that grinds food in some animals. 630

gland Epithelial cell or group of epithelial cells that are specialized to secrete a substance. 509

global climate change Predicted increase in the Earth's temperature due to human activities that promote the reradiation of solar heat toward the Earth. 770

globular stage Stage of development of a sporophyte embryo; root-shoot axis is established and dermal tissue is formed. 496

glomerular capsule (gluh-mair-yuh-lur) Double-walled cup that surrounds the glomerulus at the beginning of the nephron. 671

glomerular filtrate Filtered portion of blood contained within the glomerular capsule. 672

glomerular filtration Movement of small molecules from the glomerulus into the glomerular capsule due to the action of blood pressure. 672

glomerulus (gluh-mair-uh-lus, gloh-mair-yuh-lus) Cluster; for example, the cluster of capillaries surrounded by the glomerular capsule in a nephron, where glomerular filtration takes place. 671

glottis (glaht-us) Opening for airflow in the larynx. 633, 654

glucagon (gloo-kuh-gahn) Hormone secreted by the pancreas that causes the liver to break down glycogen and raises the blood glucose level. 692

glucocorticoid (gloo-koh-kor-tih-koyd) Type of hormone secreted by the adrenal cortex that influences carbohydrate, fat, and protein metabolism; see cortisol. 690

glucose (gloo-kohs) Six-carbon sugar that organisms degrade as a source of energy during cellular respiration. 47

glycerol Three-carbon carbohydrate with three hydroxyl groups attached; a component of fats and oils. 49

glycogen (gly-koh-jun) Storage polysaccharide that is composed of glucose molecules joined in a linear fashion but having numerous branches. 48

glycolipid Lipid in plasma membranes that bears a carbohydrate chain attached to a hydrophobic tail. 93

glycolysis Anaerobic breakdown of glucose that results in a gain of two ATP. 125, 126

glycoprotein Protein in plasma membranes that bears a carbohydrate chain. 93

gnetophyte Member of one of the four phyla of gymnosperms; Gnetophyta has only three living genera, which differ greatly from one another—e.g., *Welwitschia* and *Ephedra*. 362

Golgi apparatus (gohl-jee) Organelle, consisting of saccules and vesicles, that processes, packages, and distributes molecules about or from the cell. 73

gonad (goh-nad) Organ that produces gametes; the ovary produces eggs, and the testis produces sperm. 700

gonadotropic hormone (goh-nad-uh-trahp-ic, -troh-pic) Chemical signal secreted by the anterior pituitary that regulates the activity of the ovaries and testes; principally, follicle-stimulating hormone (FSH) and luteinizing hormone (LH). 686

gonorrhea (gahn-nuh-ree-uh) Sexually transmitted disease caused by the bacterium *Neisseria gonorrhoeae* that can lead to pelvic inflammatory disease. 708

granum (pl., grana) Stack of chlorophyll-containing thylakoids in a chloroplast. 107

gravitational balance Maintenance of balance when the head and body are motionless. 562

gravitropism Growth response of roots and stems of plants to the Earth's gravity; roots demonstrate positive gravitropism, and stems demonstrate negative gravitropism. 476

gray crescent Gray area that appears in an amphibian egg after being fertilized by the sperm; thought to contain chemical signals that turn on the genes that control development. 713

gray matter Nonmyelinated axons and cell bodies in the central nervous system. 534

grazing food web Complex pattern of interlocking and crisscrossing food chains that begins with populations of autotrophs serving as producers. 772

green algae Members of a diverse group of photosynthetic protists; contain chlorophylls *a* and *b* and have other biochemical characteristics like those of plants. 345

greenhouse gases Gases involved in the reradiation of solar heat toward the Earth, sometimes called the greenhouse effect. 776

ground tissue Tissue that constitutes most of the body of a plant; consists of parenchyma, collenchyma, and sclerenchyma cells that function in storage, basic metabolism, and support. 436

growth hormone (GH) Substance secreted by the anterior pituitary; controls the size of an individual by promoting cell division, protein synthesis, and bone growth. 687

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guard cell One of two cells that surround a leaf stoma; changes in the turgor pressure of these cells cause the stoma to open or close. 456

guttation Liberation of water droplets from the edges and tips of leaves. 454

gymnosperm Type of woody seed plant in which the seeds are not enclosed by fruit and are usually borne in cones, such as those of the conifers. 362

H

H1N1 virus Emerging virus that causes a flu commonly called swine flu. 313

habitat Place where an organism lives and is able to survive and reproduce. 728, 760

habituation Simplest form of learning, in which an animal learns not to respond to irrelevant stimuli. 747

halophile Type of archaean that lives in extremely salty habitats. 325

haploid life cycle Presence of one of each type of chromosome during meiosis of the cell cycle. 160, 345

haploid (n) number (hap-loyd) The n number of chromosomesomes—half the diploid number; the number characteristic of gametes, which contain only one set of chromosomes. 146

hard palate (pal-it) Bony, anterior portion of the roof of the mouth. 632

Hardy-Weinberg principle Law stating that the gene frequencies in a population remain stable if evolution does not occur due to nonrandom mating, selection, migration, and genetic drift. 260

hay fever Seasonal variety of allergic reaction to a specific allergen. Characterized by sudden attacks of sneezing, swelling of nasal mucosa, and often asthmatic symptoms. 622

heart murmur Clicking or swishy sounds, often due to leaky valves. 592

heart stage Stage of development of a sporophyte embryo; cotyledons appear. 496

heat Type of kinetic energy; captured solar energy eventually dissipates as heat in the environment. 86

helper T cell T lymphocyte that secretes cytokines that stimulate all kinds of immune system cells. 616

heme Iron-containing portion of a hemoglobin molecule. 658

hemocoel Residual coelom found in molluscs and arthropods that is filled with hemolymph. 590

hemodialysis (he-moh-dy-al-uh-sus) Cleansing of blood by using an artificial membrane that causes substances to diffuse from blood into a dialysis fluid. 676

hemoglobin (Hb) (hee-muh-gloh-bun) Iron-containing pigment in red blood cells that combines with and transports oxygen. 600, 658

hemolymph Circulatory fluid that is a mixture of blood and tissue fluid; seen in animals that have an open circulatory system, such as molluscs and arthropods. 590

hemophilia Most common of the severe clotting disorders caused by the absence of a blood clotting factor. 603

hepatic portal system Pathway of blood flow between intestinal capillaries and liver capillaries. 598

herbaceous Nonwoody stem. 438

herbivore (ur-buh-vor) Primary consumer in a grazing food chain; a plant eater. 770

hermaphrodite Animal having both male and female sex organs. 387

herpes simplex virus (HSV) Virus that causes genital herpes, a sexually transmitted disease. 708

heterochromatin Highly compacted chromatin that is not accessible for transcription. 214

heterocyst Cyanobacterial cell that synthesizes a nitrogen-fixing enzyme when nitrogen supplies dwindle. 324

heterotroph Organism that cannot synthesize organic molecules from inorganic nutrients and therefore must take in organic nutrients (food). 106, 770

heterozygote advantage Situation in which individuals heterozygous for a trait have a selective advantage over those who are homozygous; an example is sickle-cell anemia. 266

heterozygous Possessing unlike alleles for a particular trait. 173

hinge joint Type of joint that allows movement as a hinge does, such as the movement of the knee. 577

hippocampus (hip-uh-kam-pus) Portion of the limbic system where memories are stored. 538

histamine (his-tuh-meen, -mun) Substance, produced by basophils in blood and mast cells in connective tissue, that causes capillaries to dilate. 614

histone Protein molecule responsible for packing chromatin. 214

HIV provirus Viral DNA that has been integrated into host cell DNA. 315

homeobox 180-nucleotide sequence located in all homeotic genes. 216

homeostasis (hoh-mee-oh-stay-sis) Maintenance of normal internal conditions in a cell or an organism by means of self-regulating mechanisms. 445, 516

hominid Classification category that includes the great apes, humans, and species very closely related to humans. 410

hominin Classification category that includes chimpanzees, humans, and species very closely related to humans. 415

hominoid Classification category that includes all apes, humans, and species very closely related to humans. 414

homologous chromosome (hoh-mahl-uh-gus, huh-mahl-uh-gus) Member of a pair of chromosomes that are alike and come together in synapsis during prophase of the first meiotic division. 155

homologous pair Chromosomes that are the same length, with the centromere occurring in the same position and having genetic information for the same traits. Each member of the pair is a homologue to the other member. 144

homologous structure Structure that is similar in two or more species because of common ancestry. 257, 303

homozygote advantage Situation in which individuals homozygous for a trait have a selective advantage over those who are heterozygous. 266

homozygous Possessing two identical alleles for a particular trait. 173

horizon Major layer of soil visible in vertical profile; for example, topsoil is the A horizon. 462

hormone Chemical signal produced in one part of an organism that controls the activity of other parts. 446, 682

horsetail Division of seedless vascular plants having only one genus *(Equisetum)* in existence today; characterized by rhizomes, scalelike leaves, strobili, and tough, rigid stems. 359

Hox gene Gene that controls the overall body plan by controlling the fate of groups of cells during development. 216

human chorionic gonadotropin (HCG) (kor-ee-ahn-ik goh-nad-uh-trahp-in, -troh-pin) Hormone produced by the chorion that functions to maintain the uterine lining. 716

Human Genome Project (HGP) Initiative to determine the complete sequence of the human genome and to analyze this information. 238

human papillomavirus (HPV) Virus that causes genital warts, a common sexually transmitted disease; also linked to cervical cancer. 708

humus Decomposing organic matter in the soil. 462

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Huntington disease Genetic disease marked by progressive deterioration of the nervous system due to deficiency of a neurotransmitter. 535

hyaline cartilage Cartilage whose cells lie in lacunae separated by a white translucent matrix containing very fine collagen fibers. 511

hydrogen bond Weak bond that arises between a slightly positive hydrogen atom of one molecule and a slightly negative atom of another or between parts of the same molecule. 32

hydrogen ion (H^+) Hydrogen atom that has lost its electron and therefore bears a positive charge. 36

hydrolysis reaction (hy-drahl-ih-sis re-ak-shun) Splitting of a compound by the addition of water, with the H^+ being incorporated in one fragment and the OH^- in the other. 46

hydrophilic (hy-druh-fil-ik) Type of molecule that interacts with water by dissolving in water and/or forming hydrogen bonds with water molecules. 34, 45

hydrophobic (hy-druh-foh-bik) Type of molecule that does not interact with water because it is nonpolar. 34, 45

hydroponics Technique for growing plants by suspending them with their roots in a nutrient solution. 460

hydrostatic skeleton Fluid-filled body compartment that provides support for muscle contraction resulting in movement; seen in cnidarians, flatworms, roundworms, and segmented worms. 570

hydrothermal vent Hot springs in the seafloor along ocean ridges where heated sea water and sulfate react to produce hydrogen sulfide; here, chromosynthetic bacteria support a community of varied organisms. 793

hydroxide ion (OH^-) One of two ions that results when a water molecule dissociates; it has gained an electron, and therefore bears a negative charge. 36

hypersensitive response (HR) Plants respond to pathogens by selectively killing plant cells to block the spread of the pathogen. 483

hypertension Elevated blood pressure, particularly the diastolic pressure. 596

hypertonic solution Higher solute concentration (less water) than the cytoplasm of a cell; causes cell to lose water by osmosis. 97

hypha (pl., hyphae) Filament of the vegetative body of a fungus. 370

hypothalamic-releasing hormone One of several hormones produced by the hypothalamus that stimulates the secretion of an anterior pituitary hormone. 686

hypothalamus (hy-poh-thal-uh-mus) Part of the brain located below the thalamus that helps regulate the internal environment of the body and produces releasing factors that control the anterior pituitary. 536

hypothesis (hy-pahth-ih-sis) Supposition that is formulated after making an observation; it can be tested by obtaining more data, often by experimentation. 4

hypotonic solution Lower solute (more water) concentration than the cytoplasm of a cell; causes cell to gain water by osmosis. 97

I

immediate allergic response Allergic response that occurs within seconds of contact with an allergen; caused by the attachment of the allergen to IgE antibodies. 622

immune system All the cells in the body that protect the body against foreign organisms and substances and also cancerous cells. 517

immunity Ability of the body to protect itself from foreign substances and cells, including disease-causing agents. 612

immunization (im-yuh-nuh-zay-shun) Use of a vaccine to protect the body against specific disease-causing agents. 617

immunoglobulin (Ig) (im-yuh-noh-glahb-yuh-lin, -yoo-lin) Globular plasma protein that functions as an antibody. 617

implantation Attachment and penetration of the embryo into the lining of the uterus (endometrium). 715

imprinting Learning to make a particular response to only one type of animal or object. 746

inclusive fitness Fitness that results from personal reproduction and from helping nondescendant relatives reproduce. 750

incomplete dominance Inheritance pattern in which the offspring has an intermediate phenotype, as when a red-flowered plant and a white-flowered plant produce pink-flowered offspring. 182

indehiscent Remaining closed at maturity, as are many fruits. 497

independent assortment Alleles of unlinked genes segregate independently of each other during meiosis so that the gametes contain all possible combinations of alleles. 156

induced fit model Change in the shape of an enzyme's active site that enhances the fit between the active site and its substrate(s). 90

induction Ability of a chemical or a tissue to influence the development of another tissue. 714

industrial melanism Increased frequency of a darkly pigmented (melanic) form in a population when predators more easily see and capture the lightly pigmented form because it is more visible against vegetation that has turned dark due to industrial pollution. 260

inflammatory response Tissue response to injury that is characterized by redness, swelling, pain, and heat. 614

ingroup In cladistics, the organisms whose relationships will be determined by shared derived characteristics. 300

initiation During DNA replication or transcription, initiation is the step whereby DNA replication begins or transcription begins; this step is catalyzed by specific enzymes such that the DNA "unravels" and forms a bubble. 202

inner ear Portion of the ear consisting of a vestibule, semicircular canals, and the cochlea where equilibrium is maintained and sound is transmitted. 559

insect Member of a group of arthropods in which the head has antennae, compound eyes, and simple eyes; the thorax has three pairs of legs and often wings; and the abdomen has internal organs. 396

insight learning Ability to apply prior learning to a new situation without trial-and-error activity. 747

inspiration (in-spuh-ray-shun) Act of taking air into the lungs; also called inhalation. 656

insulin (in-suh-lin) Hormone secreted by the pancreas that lowers the blood glucose level by promoting the uptake of glucose by cells and the conversion of glucose to glycogen by the liver and skeletal muscles. 692

integration Summing up of excitatory and inhibitory signals by a neuron or by some part of the brain. 531, 551

integumentary system Organ system consisting of skin and various organs, such as hair, that are found in skin. 516

intercalated disks Region that holds adjacent cardiac muscle cells together and appears as dense bands at right angles to the muscle striations. 512

interferon (in-tur-feer-ahn) Antiviral agent produced by an infected cell that blocks the infection of another cell. 613

interkinesis Period of time between meiosis I and meiosis II during which no DNA replication takes place. 155, 159

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intermediate filaments Ropelike assemblies of fibrous polypeptides in the cytoskeleton that provide support and strength to cells; so called because they are intermediate in size between actin filaments and microtubules. 78

internal respiration Exchange of oxygen and carbon dioxide between blood and tissue fluid. 650

intermembrane space Space between the inner and outer membranes of a mitochondrion where hydrogen ions collect prior to passing through an ATP synthase complex. 128

interneuron Neuron located within the central nervous system that conveys messages between parts of the central nervous system. 527

internode In vascular plants, the region of a stem between two successive nodes. 432

interphase Portion of the cell cycle that includes the G_1, S, and G_2 stages but not the mitotic stage. 145

interspersed repeat Sequence of DNA nucleotides that is repeated in several different regions of the same chromosome or across multiple chromosomes. 240

intertidal zone Region along a coastline where the tide recedes and returns. 792

intervertebral disk (in-tur-vur-tuh-brul) Layer of cartilage located between adjacent vertebrae. 573

intron Segment of a gene that does not code for a protein. 199, 239

inversion Change in chromosome structure in which a segment of a chromosome is turned around 180 degrees; this reversed sequence of genes can lead to altered gene activity and abnormalities. 164

invertebrate An animal without a serial arrangement of vertebrae. 384

invertebrate chordate Chordate in which the notochord is never replaced by the vertebral column. 398

ion (eye-un, -ahn) Charged particle that carries a negative or positive charge. 30

ionic bond (eye-ahn-ik) Chemical bond in which ions are attracted to one another by opposite charges. 30

iris (eye-ris) Muscular ring that surrounds the pupil and regulates the passage of light through this opening. 554

isomers Molecules with the same molecular formula but a different structure, and therefore a different shape. 45

isotonic solution Solution that is equal in solute concentration to that of the cytoplasm of a cell; causes cell to neither lose nor gain water by osmosis. 97

isotope (eye-suh-tohp) One of two or more atoms with the same atomic number but a different atomic mass due to the number of neutrons. 27

J

jawless fish Type of fish that has no jaws; includes today's hagfishes and lampreys. 400

K

karyotype (kar-ee-uh-typ) Duplicated chromosomes arranged by pairs according to their size, shape, and general appearance. 144

keystone species Species whose activities significantly affect community structure. 810

kidneys Paired organs of the vertebrate urinary system that regulate the chemical composition of the blood and produce a waste product called urine. 670

kilocalorie Caloric value of food; 1,000 calories. 86

kinetic energy Energy associated with motion. 86

kinetochore Disk-shaped structure within the centromere of a chromosome to which spindle microtubules become attached during mitosis and meiosis. 147

kingdom One of the categories used to classify organisms; the category above phylum. 14, 296

kin selection Indirect selection; adaptation to the environment due to the reproductive success of an individual's relatives. 750

Klinefelter syndrome Condition caused by the inheritance of XXY chromosomes. 163

Krebs cycle Cycle of reactions in mitochondria that begins with citric acid; it breaks down an acetyl group as CO_2, ATP, NADH, and $FADH_2$ are given off; also called the citric acid cycle. 125, 129

L

lacteal (lak-tee-ul) Lymphatic vessel in an intestinal villus; it aids in the absorption of lipids. 610, 635

lacuna Small pit or hollow cavity, as in bone or cartilage, where a cell or cells are located. 511, 576

ladderlike nervous system In planarians, two lateral nerve cords joined by transverse nerves. 387, 532

lake Body of fresh water, often classified by nutrient status, such as oligotrophic (nutrient-poor) or eutrophic (nutrient-rich). 791

lancelet Invertebrate chordate with a body that resembles a lancet and has the four chordate characteristics as an adult. 398

land fungi Fungi (zygospore, sac, and club) that live on land and reproduce by producing windblown spores. 370

landscape diversity Variety of habitat elements within an ecosystem (e.g., plains, mountains, and rivers). 801

large intestine Last major portion of the digestive tract, extending from the small intestine to the anus and consisting of the cecum, the colon, the rectum, and the anal canal. 636

larva Immature form in the life cycle of some animals; it sometimes undergoes metamorphosis to become the adult form. 387, 700

larynx (lar-ingks) Cartilaginous organ located between the pharynx and the trachea that contains the vocal cords; also called the voice box. 654

law of independent assortment During gametogenesis, each pair of alleles assorts (separates) independently of other pairs, and therefore all possible combinations of alleles can occur in the gametes. 174

leaf Lateral appendage of a stem, highly variable in structure, often containing cells that carry out photosynthesis. 432

learning Relatively permanent change in behavior that results from practice and experience. 746

legume Plant with root nodules containing bacteria able to fix atmospheric nitrogen. 6

lens Clear, membranelike structure found in the eye behind the iris; brings objects into focus. 554

lenticel Frond of usually numerous, slightly raised, somewhat spongy groups of cells in the bark of woody plants. Permits gas exchange between the interior of a plant and the external atmosphere. 442

less-developed country (LDC) Country that is becoming industrialized; typically, population growth is expanding rapidly, and the majority of people live in poverty. 737

lichen Symbiotic relationship between certain fungi and algae, in which the fungi possibly provide inorganic food or water and the algae provide organic food. 324, 371

life history Adaptations in characteristics that influence an organism's biology, such as how many offspring it produces, its survival, and factors such as age and size that determine its reproductive maturity. 735

ligament Tough cord or band of dense fibrous connective tissue that joins bone to bone at a joint. 511

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limbic system Association of various brain centers, including the amygdala and hippocampus; governs learning and memory and various emotions, such as pleasure, fear, and happiness. 538

limiting factor Resource or environmental condition that restricts the abundance and distribution of an organism. 729

linkage group Alleles of different genes that are located on the same chromosome and tend to be inherited together. 173

Linnaean classification Use of traditional categories (domain, kingdom, phylum, class order, family, and genus) to group organisms according to anatomical and genetic homologies. 296

lipase Fat-digesting enzyme secreted by the pancreas. 634

lipid (lip-id, ly-pid) Class of organic compounds that tends to be soluble only in nonpolar solvents such as alcohol; includes fats and oils. 49

liposome Droplet of phospholipid molecules formed in a liquid environment. 319

liver Large, dark red internal organ that produces urea and bile, detoxifies the blood, stores glycogen, and produces the plasma proteins, among other functions. 638

lobe-finned fish Type of fish with limblike fins. 401

logistic growth Population increase that results in an S-shaped curve; growth is slow at first, steepens, and then levels off due to environmental resistance. 732

long-day plant Plant that flowers when day length is longer than a critical length (e.g., wheat, barley, clover, spinach). 481

loop of the nephron (nef-rahn) Portion of the nephron lying between the proximal convoluted tubule and the distal convoluted tubule that functions in water reabsorption. 671

loose fibrous connective tissue Tissue composed mainly of fibroblasts widely separated by a matrix containing collagen and elastic fibers. 510

lumen Cavity inside any tubular structure, such as the lumen of the digestive tract. 509

lungs Paired, cone-shaped organs within the thoracic cavity; function in internal respiration and contain moist surfaces for gas exchange. 651

luteal phase Second half of the ovarian cycle, during which the corpus luteum develops and much progesterone (and some estrogen) is produced. 706

luteinizing hormone (LH) Hormone produced by the anterior pituitary gland that stimulates the development of the corpus luteum in females and the production of testosterone in males. 703

lymph (limf) Fluid, derived from tissue fluid, that is carried in lymphatic vessels. 511, 602, 610

lymphatic (lymphoid) organ Organ other than a lymphatic vessel that is part of the lymphatic system; includes lymph nodes, tonsils, spleen, thymus gland, and bone marrow. 611

lymphatic system Organ system consisting of lymphatic vessels and lymphatic organs that transports lymph and lipids and aids the immune system. 517, 610

lymphatic vessel Vessel that carries lymph. 610

lymph node Mass of lymphatic tissue located along the course of a lymphatic vessel. 611

lymphocyte (lim-fuh-syt) Specialized white blood cell that functions in specific defense; occurs in two forms—T lymphocyte and B lymphocyte. 601

lysogenic cycle Bacteriophage life cycle in which the virus incorporates its DNA into that of a bacterium; occurs preliminary to the lytic cycle. 311

lysosome (ly-suh-sohm) Membrane-bounded vesicle that contains hydrolytic enzymes for digesting macromolecules. 74

lytic cycle Bacteriophage life cycle in which the virus takes over the operation of the bacterium immediately upon entering it and subsequently destroys the bacterium. 311

M

macroevolution Large-scale evolutionary change, such as the formation of new species. 272

macronutrient Essential element needed in large amounts for plant growth, such as nitrogen, calcium, or sulfur. 460

macrophage (mak-ruh-fayj) Large phagocytic cell derived from a monocyte that ingests microbes and debris. 613

malaria Serious infectious illness caused by the parasitic protozoan *Plasmodium*. Malaria is characterized by bouts of chills and high fever that occur at regular intervals. 341

male gametophyte In seed plants, the gametophyte that produces sperm; a pollen grain. 363, 490

Malpighian tubule Blind, threadlike excretory tubule near the anterior end of an insect's hindgut. 667

mammal Homeothermic vertebrate characterized especially by the presence of hair and mammary glands. 404

marsupial Member of a group of mammals bearing immature young nursed in a marsupium, or pouch (e.g., kangaroo and opossum). 404

mass extinction Episode of large-scale extinction in which large numbers of species disappear in a few million years or less. 292

mast cell Cell to which antibodies attach, causing it to release histamine, thus producing allergic symptoms. 612

master developmental regulatory genes Genes that regulate the transcription of other genes so that development can proceed normally. 216

maternal inheritance Type of inheritance in which all offspring have the genotype and phenotype of only the female parent; exemplified by mitochondrial genes because mitochondria are passed to offspring only from the mother, not the father. 423

matrix (may-triks) Unstructured semifluid substance that fills the space between cells in connective tissues or inside organelles. 128, 510

matter Anything that takes up space and has mass. 26

mature embryo Sporophyte embryo after all the stages of development. 496

mechanoreceptor (mek-uh-noh-rih-sep-tur) Sensory receptor that responds to mechanical stimuli, such as that from pressure, sound waves, or gravity. 550

medulla oblongata (muh-dul-uh ahb-lawng-gah-tuh) Part of the brain stem that is continuous with the spinal cord; controls heartbeat, blood pressure, breathing, and other vital functions. 536

megaspore One of the two types of spores produced by seed plants; develops into a female gametophyte (embryo sac). 366

meiosis, meiosis I, meiosis II (my-oh-sis) Type of nuclear division that occurs as part of sexual reproduction, in which the daughter cells receive the haploid number of chromosomes in varied combinations. 155

melanocyte-stimulating hormone (MSH) Substance that causes melanocytes to secrete melanin in lower vertebrates. 687

melatonin (mel-uh-toh-nun) Hormone, secreted by the pineal gland, that is involved in biorhythms. 693

membrane attack complex Group of complement proteins that form channels in a microbe's surface, thereby destroying it. 612

memory Capacity of the brain to store and retrieve information about past sensations and perceptions; essential to learning. 538

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memory B cell Forms during a primary immune response but enters a resting phase until a secondary immune response occurs. 617
memory T cell T cell that differentiates during an initial infection and responds rapidly during subsequent exposure to the same antigen. 618
meninges (sing., meninx) (muh-nin-jeez) Protective membranous coverings about the central nervous system. 534
meningitis Condition that refers to inflammation of meninges that cover the brain and spinal cord. 534
meniscus (pl., menisci) (muh-nis-kus,-kee, -sy) Cartilaginous wedges that separate the surfaces of bones in synovial joints. 577
menstruation (men-stroo-ay-shun) Loss of blood and tissue from the uterus at the end of a uterine cycle. 706
meristem tissue Undifferentiated, embryonic tissue in the active growth regions of plants. 353, 440
mesoderm Middle primary tissue layer of an animal embryo that gives rise to muscle, several internal organs, and connective tissue layers. 711
mesoglea In animals with only two tissue layers, a transparent, jellylike packing material that occurs between the ectoderm and the endoderm. 386
mesophyll Inner, thickest layer of a leaf consisting of palisade and spongy mesophyll; the site of most photosynthesis. 438
messenger RNA (mRNA) Type of RNA formed from a DNA template that bears coded information for the amino acid sequence of a polypeptide. 57, 199
metabolic pathway Series of linked reactions, beginning with a particular reactant and terminating with an end product. 92
metabolic pool Metabolites that are the products of and/or substrates for key reactions in cells, allowing one type of molecule to be changed into another type, such as carbohydrates converted to fats. 135
metabolism All of the chemical reactions that occur in a cell. 9
metapopulation Population subdivided into several small, isolated populations due to habitat fragmentation. 810
metastasis (muh-tas-tuh-sis) Spread of cancer from the place of origin throughout the body; caused by the ability of cancer cells to migrate and invade tissues. 153, 223
methanogen Type of archaean that lives in oxygen-free habitats, such as swamps, and releases methane gas. 325
MHC (major histocompatibility complex) protein Protein marker that is a part of cell-surface markers anchored in the plasma membrane, which the immune system uses to identify "self." 618
microevolution Change in gene frequencies between populations of a species over time. 259
micronutrient Essential element needed in small amounts for plant growth, such as boron, copper, and zinc. 460
microRNAs (miRNA) Type of small RNA that may bind to mRNA and thereby regulate its activity following transcription. 219
microspores One of two types of spores produced by seed plants; develops into a male gametophyte (pollen grain). 366
microtubule (my-kro-too-byool) Small, cylindrical structure that contains 13 rows of the protein tubulin surrounding an empty central core; present in the cytoplasm, centrioles, cilia, and flagella. 78
microvillus Cylindrical process that extends from an epithelial cell of a villus of the intestinal wall and serves to increase the surface area of the cell. 635
midbrain Part of the brain located below the thalamus and above the pons; contains reflex centers and tracts. 536
middle ear Portion of the ear consisting of the tympanic membrane, the oval and round windows, and the ossicles; where sound is amplified. 559
mimicry Superficial resemblance of two or more species; a mechanism that avoids predation by appearing to be noxious. 763
mineral Naturally occurring inorganic substance containing two or more elements; certain minerals are needed in the diet. 460, 641
mineralocorticoid (min-ur-uh-loh-kor-tih-koyd) Type of hormone secreted by the adrenal cortex that regulates salt and water balance, leading to increases in blood volume and blood pressure. 690
mitochondrion (mite-oh-KAHN-dree-uhn) Membrane-bounded organelle in which ATP molecules are produced during the process of cellular respiration. 76
mitosis (my-toh-sis) Type of cell division in which daughter cells receive the exact chromosomal and genetic makeup of the parent cell; occurs during growth and repair. 145
model Stand-in for an experimental subject that is not available for experimentation. 5
model of island biogeography Model developed by ecologists Robert MacArthur and E. O. Wilson to explain the effects of distance from the mainland and size of an island on its diversity. 769
molecular clock Mutational changes that accumulate at a presumed constant rate in regions of DNA not involved in adaptation to the environment. 304
molecule Union of two or more atoms of the same element; also, the smallest part of a compound that retains the properties of the compound. 9, 29
molting Periodic shedding of the exoskeleton in arthropods. 393
monoclonal antibody One of many antibodies produced by a clone of hybridoma cells that all bind to the same antigen. 620
monocot Abbreviation of monocotyledon. Flowering plant group; among other characteristics, members have one embryonic leaf, parallel-veined leaves, and scattered vascular bundles. 365, 434
monocotyledones Class of flowering plants characterized by one embryonic leaf, parallel-veined leaves, and scattered vascular bundles. 365
monocyte (mahn-uh-syt) Type of agranular white blood cell that functions as a phagocyte and an antigen-presenting cell. 601
monohybrid cross Single genetic cross involving only one trait, such as flower color. 172
monomer Small molecule that is a subunit of a polymer—e.g., glucose is a monomer of starch. 46
monosaccharide (mahn-uh-sak-uh-ryd) Simple sugar; a carbohydrate that cannot be decomposed by hydrolysis (e.g., glucose). 47
monosomy One less chromosome than usual. 162
monotreme Egg-laying mammal (e.g., duckbill platypus and spiny anteater). 404
monsoon Climate in India and southern Asia caused by wet ocean winds that blow onshore for almost half the year. 783
more-developed country (MDC) Country that is industrialized; typically, population growth is low, and the people enjoy a good standard of living. 737
morphogenesis Emergence of shape in tissues, organs, or entire embryo during development. 713
morula Spherical mass of cells resulting from cleavage during animal development prior to the blastula stage. 710
moss Type of bryophyte. 356

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motor neuron Nerve cell that conducts nerve impulses away from the central nervous system and innervates effectors (muscles and glands). 527

motor unit Motor neuron and all the muscle fibers it innervates. 580

M stage In the cell cycle, the period of time during which mitosis occurs to produce daughter cells. 145

multifactorial trait Trait or illness determined by several genes and the environment. 183

multiple alleles (uh-leelz) Inheritance pattern in which there are more than two alleles for a particular trait; each individual has only two of all possible alleles. 182

multiple fruit Cluster of mature ovaries produced by a cluster of flowers, as in a pineapple. 497

muscle dysmorphia Mental state in which a person thinks his or her body is underdeveloped, and becomes preoccupied with body building and diet; affects more men than women. 644

muscular system System of muscles that produces movement within the body and movement of its limbs; principal components are skeletal muscle, smooth muscle, and cardiac muscle. 516

muscular tissue Type of tissue composed of fibers that can shorten and thicken. 512

mutate To undergo a permanent genetic change. 10

mutation Alteration in chromosome structure or number; also, alteration in a gene due to a change in DNA composition. 152, 261

mutualism Symbiotic relationship in which both species benefit in terms of growth and reproduction. 766

mycelium Mass of hyphal filaments composing the vegetative body of a fungus. 370

mycorrhizae Mutually beneficial symbiotic relationship between a fungus and the roots of vascular plants. 371, 464

myelin sheath (my-uh-lin) White, fatty material, derived from the membrane of Schwann cells, that forms a covering for nerve fibers. 527

myofibril (my-uh-fy-brul) Contractile portion of muscle cells that contains a linear arrangement of sarcomeres and shortens to produce muscle contraction. 582

myosin (my-uh-sin) One of two major proteins of muscle; makes up thick filaments in myofibrils of muscle fibers. (See actin.) 582

myxedema (mik-sih-dee-muh) Condition resulting from a deficiency of thyroid hormone in an adult. 689

N

N_2 (nitrogen) fixation Process whereby free atmospheric nitrogen is converted into compounds, such as ammonium and nitrates, usually by bacteria. 775

NAD^+ Nicotinamide adenine dinucleotide; coenzyme of oxidation-reduction that accepts electrons and hydrogen ions to become $NADH + H^+$ as oxidation of substrates occurs. During cellular respiration, NADH carries electrons to the electron transport chain in mitochondria. 124

nasopharynx (nay-zoh-far-ingks) Region of the pharynx associated with the nasal cavity. 633

natural killer (NK) cell Lymphocyte that causes an infected or cancerous cell to burst. 613

natural selection Mechanism resulting in adaptation to the environment. 16, 252

negative feedback Mechanism of homeostatic response by which the output of a system suppresses or inhibits activity of the system. 519, 682

nematocyst In cnidarians, a capsule that contains a threadlike fiber whose release aids in the capture of prey. 386

nephridia Segmentally arranged, paired excretory tubules of many invertebrates, as in the earthworm. 392, 667

nephron (nef-rahn) Microscopic kidney unit that regulates blood composition by glomerular filtration, tubular reabsorption, and tubular secretion. 670

nerve Bundle of nerve fibers outside the central nervous system. 513, 539

nerve fiber Axon; conducts nerve impulses away from the cell. Nerve fibers are classified as either myelinated or unmyelinated, based on the presence or absence of a myelin sheath. 526

nerve net Diffuse, noncentralized arrangement of nerve cells in cnidarians. 532

nervous system Organ system consisting of the brain, spinal cord, and associated nerves that coordinates the other organ systems of the body. 516

nervous tissue Tissue that contains nerve cells (neurons), which conduct impulses, and neuroglia, cells that support, protect, and provide nutrients to neurons. 513

neural plate Region of the dorsal surface of the chordate embryo that marks the future location of the neural tube. 712

neural tube Tube formed by closure of the neural groove during development. In vertebrates, the neural tube develops into the spinal cord and the brain. 712

neuroglia Nonconducting nerve cells that are intimately associated with neurons and function in a supportive capacity. 513, 527

neuron Nerve cell that characteristically has three parts: dendrites, cell body, and axon. 513, 527

neurotransmitter Chemical stored at the ends of axons that is responsible for transmission across a synapse. 530

neurula The early embryo during the development of the neural tube from the neural plate, marking the first appearance of the nervous system; the next stage after the gastrula. 712

neutron (noo-trahn) Neutral subatomic particle, located in the nucleus and having a weight of approximately one atomic mass unit. 27

neutrophil (noo-truh-fill) Granular leukocyte that is the most abundant of the white blood cells; first to respond to infection. 601, 613

nitrification Process by which nitrogen in ammonia and organic molecules is oxidized to nitrites and nitrates by soil bacteria. 775

node In plants, the place where one or more leaves attach to a stem. 432, 527

node of Ranvier (rahn-vee-ay) Gap in the myelin sheath around a nerve fiber. 527

noncompetitive inhibition Form of enzyme inhibition by which the inhibitor binds to an enzyme at a location other than the active site; while at this site, the enzyme shape changes, the inhibitor is unable to bind to its substrate, and no product forms. 92

nondisjunction Failure of homologous chromosomes or daughter chromosomes to separate during meiosis I and meiosis II, respectively. 162

nonpolar covalent bond Bond in which the sharing of electrons between atoms is fairly equal. 32

nonrandom mating Mating among individuals on the basis of their phenotypic similarities or differences, rather than randomly. 261

nonrenewable resource Resource that is finite and cannot be replenished by a natural means at the same rate it is being consumed. 814

nonvascular plants Land plants (i.e., bryophytes) that have no vascular tissue and therefore are low-lying and generally found in moist locations. 356

norepinephrine (NE) (nor-ep-uh-nef-rin) Neurotransmitter of the postganglionic fibers in the sympathetic division of the autonomic nervous system; also,

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a hormone produced by the adrenal medulla. 530, 690

notochord Cartilaginous-like supportive dorsal rod in all chordates sometime in their life cycle; replaced by vertebrae in vertebrates. 398

nuclear envelope Double membrane that surrounds the nucleus and is connected to the endoplasmic reticulum; has pores that allow substances to pass between the nucleus and the cytoplasm. 70

nuclear pore Opening in the nuclear envelope that permits the passage of proteins into the nucleus and ribosomal subunits out of the nucleus. 70

nucleic acid Polymer of nucleotides; both DNA and RNA are nucleic acids. 57, 192

nucleoid An irregularly shaped region in the prokaryotic cell that contains its genetic material. 67

nucleolus (noo-klee-uh-lus, nyoo-) Dark-staining, spherical body in the cell nucleus that produces ribosomal subunits. 70

nucleosome In the nucleus of a eukaryotic cell, a unit composed of DNA wound around a core of eight histone proteins, giving the appearance of a string of beads. 214

nucleotide Monomer of DNA and RNA consisting of a 5-carbon sugar bonded to a nitrogen-containing base and a phosphate group. 56, 192

nucleus (noo-klee-us, nyoo-) Membrane-bounded organelle that contains chromosomes and controls the structure and function of the cell. 68

O

obligate anaerobe Prokaryote unable to grow in the presence of free oxygen. 323

observation Step in the scientific method by which data are collected before a conclusion is drawn. 4

obstructive pulmonary disorder Characterized by airflow restriction in the airways; includes chronic bronchitis, emphysema, and asthma. 660

octet rule States that an atom other than hydrogen tends to form bonds until it has eight electrons in its outer shell; an atom that already has eight electrons in its outer shell does not react and is inert. 29

oil Substance, usually of plant origin and liquid at room temperature, formed when a glycerol molecule reacts with three fatty acid molecules. 49

olfactory cell (ahl-fak-tuh-ree, -tree, ohl-) Modified neuron that is a sensory receptor for the sense of smell. 553

oligotrophic lake Lake with few nutrients, usually very blue. 791

omnivore (ahm-nuh-vor) Organism in a food chain that feeds on both plants and animals. 770

oncogene (ahng-koh-jeen) Cancer-causing gene. 222

oocyte Immature egg that is undergoing meiosis; upon completion of meiosis, the oocyte becomes an egg. 704

oogenesis (oh-uh-jen-uh-sis) Production of an egg in females by the process of meiosis and maturation. 705

open circulatory system Arrangement of internal transport in which blood bathes the organs directly, and there is no distinction between blood and interstitial fluid. 590

operant conditioning Learning that results from rewarding or reinforcing a particular behavior. 747

operator In an operon, the sequence of DNA that binds tightly to a repressor, and thereby regulates the expression of structural genes. 212

operon Group of structural and regulating genes that function as a single unit. 212

opportunistic population Population demonstrating a life history pattern in which members exhibit exponential population growth. Its members are small in size, mature early, have a short life span, produce many offspring, and provide little or no care to offspring (e.g., dandelions). 735

opposable thumb Fingers arranged in such a way that the thumb can touch the fingertips of all four fingers. 412

order One of the categories, or taxa, used by taxonomists to group species; the taxon above the family level. 14, 296

organ Combination of two or more different tissues performing a common function. 9, 508

organelle (or-guh-nel) Small membranous structure in the cytoplasm having a specific structure and function. 68

organic chemistry The study of carbon compounds; chemistry of the living world. 44

organism Individual living thing. 9, 508

organ of Corti Structure in the vertebrate inner ear that contains auditory receptors; also called the spiral organ. 560

organ system Group of related organs working together. 9, 508

orgasm Physiological and psychological sensations that occur at the climax of sexual stimulation. 702

osmosis (ahz-moh-sis, ahs-) Diffusion of water through a selectively permeable membrane. 97

ossicle (ahs-ih-kul) One of the small bones of the middle ear—malleus, incus, and stapes. 559

osteocyte (ahs-tee-uh-syt) Mature bone cell located within the lacunae of bone. 576

otolith One of several calcium carbonate granules associated with receptors for gravitational balance; in vertebrates, located in the utricle and saccule. 563

outer ear Portion of the ear consisting of the pinna and the auditory canal. 559

outgroup In cladistics, a group of organisms that possess at least one characteristic that is judged to be ancestral, because while it lacks the ingroup's other characteristics, it shares this one with all the members of the ingroup. 300

ovarian cycle (oh-vair-ee-un) Monthly follicle changes occurring in the ovary that control the level of sex hormones in the blood and the uterine cycle. 706

ovary In animals, the female gonad, the organ that produces eggs, estrogen, and progesterone; in flowering plants, the base of the pistil that protects ovules and, along with associated tissues, becomes a fruit. 365, 490, 700, 704

overexploitation Occurs when the number of individuals taken from a wild population is so great that the population becomes severely reduced in numbers. 809

oviduct Tube that transports oocytes to the uterus; also called a uterine tube. 704

ovulation (ahv-yuh-lay-shun, ohv-) Release of a secondary oocyte from the ovary; if fertilization occurs, the secondary oocyte becomes an egg. 705

ovule In seed plants, the structure in which the megaspore becomes an egg-producing female gametophyte; it develops into a seed following fertilization. 355

oxidation Loss of one or more electrons from an atom or molecule; in biological systems, generally the loss of hydrogen atoms. 108

oxygen debt Amount of oxygen needed to metabolize lactate, a compound that accumulates during vigorous exercise. 133, 584

oxyhemoglobin (ahk-see-hee-muh-gloh-bin) Compound formed when oxygen combines with hemoglobin. 658

oxytocin (ahk-sih-toh-sin) Hormone released by the posterior pituitary that causes contraction of the uterus and milk letdown. 686

P

p53 Protein coded for by the *p53* gene that halts the cell cycle when DNA mutates and is in need of repair. 152

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pain receptor Sensory receptor that is sensitive to chemicals released by damaged tissues or excess heat or pressure stimuli. 550

paleontologist Individual who studies fossils and the history of life. 255

paleontology Study of fossils that results in knowledge about the history of life. 250

palisade mesophyll Layer of tissue in a plant leaf containing elongated cells with many chloroplasts. 438

pancreas (pang-kree-us, pan-) Internal organ that produces digestive enzymes and the hormones insulin and glucagon. 638, 692

pancreatic amylase Enzyme that digests starch to maltose. 634

pancreatic islets (islets of Langerhans) Masses of cells that constitute the endocrine portion of the pancreas. 692

parasite Species that is dependent on a host species for survival, usually to the detriment of the host species. 764

parasitism Symbiotic relationship in which one species (the *parasite*) benefits in terms of growth and reproduction to the detriment of the other species (the *host*). 764

parasympathetic division That part of the autonomic system that is active under normal conditions; uses acetylcholine as a neurotransmitter. 541

parathyroid gland (par-uh-thy-royd) Gland embedded in the posterior surface of the thyroid gland; it produces parathyroid hormone. 689

parenchyma cell Plant tissue composed of the least-specialized of all plant cells; found in all organs of a plant. 436

parent cell Cell that divides to form daughter cells. 146

Parkinson disease Progressive deterioration of the central nervous system due to a deficiency in the neurotransmitter dopamine. 535

parsimony In cladistics, the preference for a cladogram that has the least number of branches. 301

parthenogenesis Development of an egg cell into a whole organism without fertilization. 700

partial pressure Pressure exerted by each gas in a mixture of gases. 658

partitioning in space In C_4 photosynthesis, carbon dioxide is fixed in mesophyll cells but enters the Krebs cycle in bundle sheath cells. 117

partitioning in time In CAM photosynthesis, carbon dioxide is fixed during the night and enters the Krebs cycle during the day. 117

pattern formation Positioning of cells during development that determines the final shape of an organism. 713

pectoral girdle (pek-tur-ul) Portion of the skeleton that provides support and attachment for an arm; consists of a scapula and a clavicle. 574

pedigree Graphic representation of matings and offspring over multiple generations for a particular genetic trait. 178

pelagic zone Open portion of the sea. 793

pelvic girdle Portion of the skeleton to which the legs are attached; consists of the coxal bones. 574

penis External organ in males through which the urethra passes; also serves as the organ of sexual intercourse. 702

pepsin Enzyme secreted by gastric glands that digests proteins to peptides. 634

peptide Two or more amino acids joined together by covalent bonding. 53

peptide bond Type of covalent bond that joins two amino acids. 53

peptide hormone Type of hormone that is a protein, a peptide, or derived from an amino acid. 684

peptidoglycan Unique molecule found in bacterial cell walls. 48

pericarp Outer covering of a fruit that develops from the wall of an ovary. 497

pericycle Layer of cells surrounding the vascular tissue of roots; produces branch roots. 438

periderm Protective tissue that replaces epidermis; includes cork and cork cambium. 442

peripheral nervous system (PNS) (puh-rif-ur-ul) Nerves and ganglia that lie outside the central nervous system. 526

peristalsis (pair-ih-stawl-sis) Wavelike contractions that propel substances along a tubular structure, such as the esophagus. 633

peritubular capillary network (pair-ih-too-byuh-lur) Capillary network that surrounds a nephron and functions in reabsorption during urine formation. 671

permafrost Permanently frozen ground, usually occurring in the tundra, a biome of arctic regions. 786

peroxisome Enzyme-filled vesicle in which fatty acids and amino acids are metabolized to hydrogen peroxide that is broken down to harmless products. 74

petal A flower part that occurs just inside the sepals; often conspicuously colored to attract pollinators. 365, 491

petiole Part of a plant leaf that connects the blade to the stem. 433

Peyer patches Lymphatic organs located in the small intestine. 611

P generation In genetics, the parental generation. 172

phagocytize To ingest extracellular particles by engulfing them, as amoeboid cells do. 339

phagocytosis (fag-uh-sy-toh-sis) Process by which amoeboid-type cells engulf large substances, forming an intracellular vacuole. 98

pharynx (far-ingks) Portion of the digestive tract between the mouth and the esophagus that serves as a passageway for food and also for air on its way to the trachea. 633, 654

phenotype (fee-nuh-typ) Visible expression of a genotype—for example, brown eyes or attached earlobes. 173

pheromone Chemical signal released by an organism that affects the metabolism or influences the behavior of another individual of the same species. 552, 684, 752

phloem Vascular tissue that conducts organic solutes in plants; contains sieve-tube elements and companion cells. 358, 437, 452

phloem sap Solution of sugars, nutrients, and hormones found in the phloem tissue of a plant. 452

phospholipid (fahs-foh-lip-id) Molecule that forms the bilayer of the cell's membranes; has a polar, hydrophilic head bonded to two nonpolar hydrophobic tails. 50

phospholipid bilayer Comprises the plasma membrane; each polar, hydrophilic head is bonded to two nonpolar, hydrophobic tails; contains embedded proteins. 93

photoperiodism Relative lengths of daylight and darkness that affect the physiology and behavior of an organism. 480

photosynthesis Process occurring usually within chloroplasts whereby chlorophyll-containing organelles trap solar energy to reduce carbon dioxide to carbohydrate. 9, 106

photosystem I (PSI) and photosystem II (PSII) Photosynthetic unit where solar energy is absorbed and high-energy electrons are generated; contains a pigment complex and an electron acceptor. 110

phototropism Growth response of plant stems to light; stems demonstrate positive phototropism. 471, 476

pH scale Measurement scale for hydrogen ion concentration. 37

phylogenetic (evolutionary) tree Diagram that indicates common ancestors and

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lines of descent among a group of organisms. 296

phylogeny Evolutionary history of a group of organisms. 298

phylum One of the categories, or taxa, used by taxonomists to group species; the taxon above the class level. 14, 296

phytochrome Photoreversible plant pigment that is involved in photoperiodism and other responses of plants such as etiolation. 480

phytoplankton Part of plankton containing organisms that photosynthesize, releasing oxygen to the atmosphere and serving as food producers in aquatic ecosystems. 343, 793

phytoremediation The use of plants to restore a natural area to its original condition. 457

pili Threadlike appendages that allow bacteria to attach to surfaces and to each other. 67

pineal gland (pin-ee-ul, py-nee-ul) Endocrine gland located in the third ventricle of the brain; produces melatonin. 536, 693

pinocytosis Process by which vesicle formation brings macromolecules into the cell. 98

pioneer species First species to colonize an area devoid of life. 768

pith Parenchyma tissue in the center of some stems and roots. 438

pituitary gland Endocrine gland that lies just inferior to the hypothalamus; consists of the anterior pituitary and the posterior pituitary. 686

placenta Organ formed during the development of placental mammals from the chorion and the uterine wall; allows the embryo, and then the fetus, to acquire nutrients and rid itself of wastes; produces hormones that regulate pregnancy. 404, 700, 717

placental mammal Member of the mammalian subclass characterized by the presence of a placenta during the development of an offspring. 404

planarian Free-living flatworm with a ladderlike nervous system. 387

plant Multicellular, usually photosynthetic, organism belonging to the plant kingdom. 15

plant hormone Chemical signal that is produced by various plant tissues and coordinates the activities of plant cells. 470

plant tissue culture Process of growing plant cells in the laboratory. 473

plaque (plak) Accumulation of soft masses of fatty material, particularly cholesterol, beneath the inner linings of the arteries. 596

plasma (plaz-muh) Liquid portion of blood; contains nutrients, wastes, salts, and proteins. 600

plasma cell Cell derived from a B cell that is specialized to mass-produce antibodies. 616

plasma membrane Membrane surrounding the cytoplasm that consists of a phospholipid bilayer with embedded proteins; functions to regulate the entrance and exit of molecules from the cell. 67

plasmid (plaz-mid) Self-replicating ring of accessory DNA in the cytoplasm of bacteria. 232, 322

plasmodesmata (sing., plasmodesma) In plants, cytoplasmic strands that extend through pores in the cell wall and connect the cytoplasm of two adjacent cells. 99, 437

plasmodial slime mold Free-living mass of cytoplasm that moves by pseudopods on a forest floor or in a field, feeding on decaying plant material by phagocytosis; reproduces by spore formation. 342

plasmolysis Contraction of the cell contents due to the loss of water. 97

platelet Cell fragment that is necessary to blood clotting; also called a thrombocyte. 511

pleiotropy Inheritance pattern in which one gene affects many phenotypic characteristics of the individual. 184

point mutation Alteration in a gene due to a change in a single nucleotide; results of this mutation vary. 204

polar body In oogenesis, a nonfunctional product; two to three meiotic products are of this type. 181

polar covalent bond Bond in which the sharing of electrons between atoms is unequal. 32

pollen grain In seed plants, the sperm-producing male gametophyte. 355, 363, 490

pollen sacs In flowering plants, the portions of the anther where microspore mother cells undergo meiosis to produce microspores. 365

pollen tube In seed plants, a tube that forms when a pollen grain lands on the stigma and germinates. The tube grows, passing between the cells of the stigma and the style to reach the egg inside an ovule, where fertilization occurs. 367

pollination In seed plants, the delivery of pollen to the vicinity of the egg-producing female gametophyte. 363, 494

pollution Any environmental change that adversely affects the lives and health of living things. 807

polygenic inheritance Pattern of inheritance in which a trait is controlled by several allelic pairs; each dominant allele contributes to the phenotype in an additive and like manner. 183

polymer Macromolecule consisting of covalently bonded monomers; for example, a polypeptide is a polymer of monomers called amino acids. 46

polymerase chain reaction (PCR) (pahl-uh-muh-rays, -rayz) Technique that uses the enzyme DNA polymerase to produce millions of copies of a particular piece of DNA. 238

polyp (pahl-ip) Small, abnormal growth that arises from the epithelial lining. 636

polypeptide Polymer of many amino acids linked by peptide bonds. 53

polyploid Having a chromosome number that is a multiple greater than twice that of the monoploid number. 162

polyribosome (pahl-ih-ry-buh-sohm) String of ribosomes simultaneously translating regions of the same mRNA strand during protein synthesis. 201

polysaccharide (pahl-ee-sak-uh-ryd) Polymer made from sugar monomers; the polysaccharides starch and glycogen are polymers of glucose monomers. 48

pond Freshwater basin, smaller than a lake. 791

pons (pahnz) Portion of the brain stem above the medulla oblongata and below the midbrain; assists the medulla oblongata in regulating the breathing rate. 536

population Organisms of the same species occupying a certain area. 12, 259, 728

population density The number of individuals per unit area or volume living in a particular habitat. 729

population distribution The pattern of dispersal of individuals living within a certain area. 729

portal system Pathway of blood flow that begins and ends in capillaries, such as the portal system located between the small intestine and the liver. 598

positive feedback Mechanism in which the stimulus initiates reactions that lead to an increase in the stimulus. 686

posterior pituitary Portion of the pituitary gland that stores and secretes oxytocin and antidiuretic hormone produced by the hypothalamus. 686

postzygotic isolating mechanism Anatomical or physiological difference between two species that prevents successful reproduction after mating has taken place. 275

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potential energy Stored energy as a result of location or spatial arrangement. 86

predation Interaction in which one organism (the *predator*) uses another (the *prey*) as a food source. 762

preparatory (prep) reaction Reaction that oxidizes pyruvate with the release of carbon dioxide; results in acetyl CoA and connects glycolysis to the Krebs cycle. 125, 128

prezygotic isolating mechanism Anatomical or behavioral difference between two species that prevents the possibility of mating. 274

primary growth In plants, growth that originates in the apical meristems of the shoot and root; causes the plant to increase in length. 440

primary motor area Area in the frontal lobe where voluntary commands begin; each section controls a part of the body. 535

primary somatosensory area (soh-mat-uh-sens-ree, -suh-ree) Area dorsal to the central sulcus where sensory information arrives from skin and skeletal muscles. 535

primate Member of the order Primate; includes prosimians, monkeys, apes, and hominids, all of whom have adaptations for living in trees. 412

prime mover Muscle most directly responsible for a particular movement. 580

prions Misfolded proteins that cause other proteins to also become misfolded; cause of mad cow disease and other rare diseases. 315

producer Photosynthetic organism at the start of a grazing food chain that makes its own food (e.g., green plants on land and algae in water). 770

proembryo Smaller portion of divided sporophyte embryo that, after dividing repeatedly, becomes the embryo of a plant. 496

progesterone (proh-jes-tuh-rohn) Female sex hormone that helps maintain sex organs and secondary sex characteristics. 705

prokaryotic cell (prokaryote) Organism that lacks the membrane-bounded nucleus and membranous organelles typical of eukaryotes. 14, 67

prolactin (PRL) (proh-lak-tin) Hormone secreted by the anterior pituitary that stimulates the production of milk from the mammary glands. 687

proliferative phase Phase of the uterine cycle in which there is increased production of estrogen, causing the endometrium to thicken. 706

promoter In an operon, a sequence of DNA where RNA polymerase binds prior to transcription. 212

proprioceptor Sensory receptor that responds to changes in muscle or tendon tension. 558

prosimian Group of primates that includes lemurs and tarsiers, and may resemble the first primates that evolved. 415

prostate gland (prahs-tayt) Gland located around the male urethra below the urinary bladder; adds secretions to semen. 702

protease Enzyme that digest proteins. 220

proteasome A large, cylindrical cellular structure that contains proteases and digests tagged proteins following translation. 220

protein Molecule consisting of one or more polypeptides. 10, 52, 640

proteome Collection of proteins resulting from the translation of genes into proteins. 240

proteomics The study of all proteins in an organism. 240

protist Member of the kingdom Protista. 15, 334

protocell In biological evolution, a possible cell forerunner that became a cell once it could reproduce. 318

proton Positive subatomic particle, located in the nucleus and having a weight of approximately one atomic mass unit. 27

proto-oncogene (proh-toh-ahng-koh-jeen) Normal gene that can become an oncogene through mutation. 222

protostome Group of coelomate animals in which the first embryonic opening (the blastopore) is associated with the mouth. 383

protozoan Heterotrophic, unicellular protist that moves by flagella, cilia, or pseudopodia, or is immobile. 335

proximal convoluted tubule Highly coiled region of a nephron near the glomerular capsule, where tubular reabsorption takes place. 671

pseudocoelom A body cavity lying between the digestive tract and the body wall that is incompletely lined by mesoderm. 390

pseudogene Gene copy that is nonfunctional due to a mutation. 239

pseudopod Cytoplasmic extension of amoeboid protists; used for locomotion and engulfing food. 339

pseudostratified ciliated columnar epithelium Appearance of layering in some epithelial cells when, actually, each cell touches a baseline and true layers do not exist. 509

puberty Period of life when secondary sex changes occur in humans; marked by the onset of menses in females and sperm production in males. 703

pulmonary artery (pool-muh-nair-ee, pul-) Blood vessel that takes blood away from the heart to the lungs. 592

pulmonary circuit Circulatory pathway that consists of the pulmonary trunk, the pulmonary arteries, and the pulmonary veins; takes O_2-poor blood from the heart to the lungs and O_2-rich blood from the lungs to the heart. 593, 598

pulmonary trunk Large blood vessel that divides into the pulmonary arteries; takes blood away from the heart to the lungs. 592

pulmonary vein Blood vessel that takes blood from the lungs to the heart. 592

pulse Vibration felt in arterial walls due to expansion of the aorta following ventricular contraction. 594

Punnett square Grid used to calculate the expected results of simple genetic crosses. 175

pupil (pyoo-pul) Opening in the center of the iris of the eye. 554

pyruvate End product of glycolysis; its further fate, involving fermentation or entry into a mitochondrion, depends on oxygen availability. 125

R

radial symmetry Body plan in which similar parts are arranged around a central axis, like spokes of a wheel. 381

radiolarian Member of the phylum Actinopoda bearing a glassy silicon test, usually with a radial arrangement of spines; pseudopods are external to the test. 339

rain shadow Leeward side (side sheltered from the wind) of a mountainous barrier, which receives much less precipitation than the windward side. 783

ray-finned fish Group of bony fishes with fins supported by parallel bony rays connected by webs of thin tissue. 400

receptacle Area where a flower attaches to a floral stalk. 365

receptor-mediated endocytosis Selective uptake of molecules into a cell by vacuole formation after they bind to specific receptor proteins in the plasma membrane. 98

recessive allele (uh-leel) Allele that exerts its phenotypic effect only in the homozygote; its expression is masked by a dominant allele. 173

reciprocal altruism The trading of helpful or cooperative acts, such as helping at the nest, by individuals—the animal

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that was helped will repay the debt at some later time. 751

recombinant DNA (rDNA) DNA that contains genes from more than one source. 232

recombinant DNA technology Use of DNA that contains genes from more than one source, often to produce transgenic organisms. 232

rectum (rek-tum) Terminal end of the digestive tube between the sigmoid colon and the anus. 636

red algae Marine photosynthetic protists with a notable abundance of phycobilin pigments; include coralline algae of coral reefs. 344

red blood cell (RBC) Formed element that contains hemoglobin and carries oxygen from the lungs to the tissues; erythrocyte. 511, 600

red bone marrow Blood-cell-forming tissue located in the spaces within spongy bone. 576, 611

red tide Occurs frequently in coastal areas and is often associated with population blooms of dinoflagellates. Dinoflagellate pigments are responsible for the red color of the water. Under these conditions, the dinoflagellates often produce saxitoxin, which can lead to paralytic shellfish poisoning. 343

redox reaction Oxidation-reduction reaction; one molecule loses electrons (oxidation) while another molecule simultaneously gains electrons (reduction). 108

reduced hemoglobin Hemoglobin molecule that is carrying hydrogen ions derived from carbonic acid. 658

reduction Chemical reaction that results in addition of one or more electrons to an atom, ion, or compound. Reduction of one substance occurs simultaneously with oxidation of another. 108

reflex Automatic, involuntary response of an organism to a stimulus. 540

reflex action An action performed automatically, without conscious thought (e.g., swallowing). 534, 633

refractory period (rih-frak-tuh-ree) Time following an action potential when a neuron is unable to conduct another nerve impulse. 529

regulatory gene In an operon, a gene that codes for a protein that regulates the expression of other genes. 212

renal cortex (ree-nul kor-teks) Outer portion of the kidney that appears granular. 670

renal medulla (ree-nul muh-dul-uh) Inner portion of the kidney that consists of renal pyramids. 670

renal pelvis Hollow chamber in the kidney that lies inside the renal medulla and receives freshly prepared urine from the collecting ducts. 670

renewable resource Resource that is replenished by a natural means at the same rate or faster than it is consumed. 814

renin (ren-in) Enzyme released by the kidneys that leads to the secretion of aldosterone and a rise in blood pressure. 675, 691

repolarization Recovery of a neuron's polarity to the resting potential after the neuron ceases transmitting impulses. 529

repetitive DNA Sequence of DNA nucleotides that is repeated several times in a genome. 239

repressor In an operon, protein molecule that binds to an operator, preventing transcription of structural genes. 212

reproduce To produce a new individual of the same kind. 9

reproductive cloning Production of an organism that is genetically identical to the original individual. 230

reproductive system Organ system that contains male or female organs and specializes in the production of offspring. 517

reptile Member of a class of terrestrial vertebrates characterized by internal fertilization, scaly skin, and an egg with a leathery shell; includes snakes, lizards, turtles, and crocodiles. 402

resource In economic terms, anything having potential use for creating wealth or giving satisfaction. 729

resource partitioning Mechanism that increases the number of niches by apportioning the supply of a resource such as food or living space between species. 760

respiration Sequence of events that results in gas exchange between the cells of the body and the environment. 650

respiratory center Group of nerve cells in the medulla oblongata that send out nerve impulses on a rhythmic basis, resulting in involuntary inspiration on an ongoing basis. 657

respiratory system Organ system consisting of the lungs and tubes that bring oxygen into the lungs and take carbon dioxide out. 517

resting potential Polarity across the plasma membrane of a resting neuron due to an unequal distribution of ions. 528

restoration ecology Subdiscipline of conservation biology that seeks ways to return ecosystems to their former state. 811

restriction enzyme Bacterial enzyme that stops viral reproduction by cleaving viral DNA; used to cut DNA at specific points during production of recombinant DNA. 232

retina (ret-n-uh, ret-nuh) Innermost layer of the eyeball that contains the rod cells and the cone cells. 554

retrovirus RNA virus containing the enzyme reverse transcriptase that carries out RNA-to-DNA transcription. 315

reverse transcriptase Enzyme that transcribes RNA into DNA. 315

rhizome Rootlike underground stem. 432, 499

rhodopsin (roh-dahp-sun) Light-absorbing molecule in rod cells and cone cells that contains a pigment and the protein opsin. 556

ribose Pentose sugar found in RNA. 47

ribosomal RNA (rRNA) (ry-buh-soh-mul) Type of RNA found in ribosomes where protein synthesis occurs. 200

ribosome (ry-buh-sohm) RNA and protein in two subunits; site of protein synthesis in the cytoplasm. 67

ribozyme Enzyme that carries out mRNA processing. 202, 318

rigor mortis Contraction of muscles at death due to lack of ATP. 583

river Freshwater channel that flows eventually to the oceans. 791

RNA interference Collective regulation of mRNA activity by miRNAs and siRNAs. 219

RNA (ribonucleic acid) (ry-boh-noo-klee-ik) Nucleic acid produced from covalent bonding of nucleotide monomers that contain the sugar ribose; occurs in three forms: messenger RNA, ribosomal RNA, and transfer RNA. 57, 192

root hair Extension of a root epidermal cell that increases the surface area for the absorption of water and minerals. 433, 463

root nodule Structure on a plant root that contains nitrogen-fixing bacteria. 464

root pressure Osmotic pressure caused by active movement of minerals into root cells; serves to elevate water in xylem for a short distance. 454

root system Includes the main root and any and all of its lateral (side) branches. 432

rotational balance Maintenance of balance when the head and body are suddenly moved or rotated. 562

rough ER (RER) Membranous system of tubules, vesicles, and sacs in cells; has attached ribosomes. 72

roundworm Member of the phylum Nematoda, having a cylindrical body

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with a complete digestive tract and a pseudocoelom; some forms are free-living in water and soil; many are parasitic. 393

RuBP carboxylase Enzyme that is required for carbon dioxide fixation (atmospheric CO_2 attaches to RuBP) in the Calvin cycle. 114

ruminant Cow and related mammals in which digestion of cellulose occurs in an extra stomach, or rumen, from which partially digested material can be ejected back into the mouth. 631

S

saccule (sak-yool) Saclike cavity in the vestibule of the inner ear; contains sensory receptors for gravitational equilibrium. 563

salivary amylase (sal-uh-vair-ee am-uh-lays, -layz) Secreted from the salivary glands; the first enzyme to act on starch. 632

salivary gland Gland associated with the mouth that secretes saliva. 632

salt Compound produced by a reaction between an acid and a base. 30

saltatory conduction Movement of nerve impulses from one neurolemmal node to another along a myelinated axon. 529

saprotroph Organism that secretes digestive enzymes and absorbs the resulting nutrients back across the plasma membrane. 323

sarcolemma (sar-kuh-lem-uh) Plasma membrane of a muscle fiber; also forms the tubules of the T system involved in muscular contraction. 582

sarcomere (sar-kuh-mir) One of many units, arranged linearly within a myofibril, whose contraction produces muscle contraction. 582

sarcoplasmic reticulum (sar-kuh-plaz-mik rihtik-yuh-lum) Smooth endoplasmic reticulum of skeletal muscle cells; surrounds the myofibrils and stores calcium ions. 582

SARS Severe acute respiratory syndrome caused by a virus that emerged in China and spread around the world. 313

saturated fatty acid Fatty acid molecule that lacks double bonds between the atoms of its carbon chain. 49

savanna Terrestrial biome that is a grassland in Africa, characterized by few trees and a severe dry season. 789

scanning electron microscope Beam of electrons scans over a specimen point by point and builds up an image on a fluorescent screen. 66

scavenger Animal that specializes in the consumption of dead animals. 770

Schwann cell Cell that surrounds a fiber of a peripheral nerve and forms the myelin sheath. 527

scientific theory Concept supported by a broad range of observations, experiments, and conclusions. 5

sclera (skleer-uh) White, fibrous, outer layer of the eyeball. 554

sclerenchyma cell Plant tissue composed of cells with heavily lignified cell walls; functions in support. 437

seaweed Multicellular forms of red, green, and brown algae found in marine habitats. 344

secondary growth In vascular plants, an increase in stem and root diameter made possible by cell division of the lateral meristems. 442

secondary metabolite Molecule not directly involved in growth, development, or reproduction of an organism; in plants, these molecules, which include nicotine, caffeine, tannins, and menthols, can discourage herbivores. 482

secondary sex characteristic Trait that is sometimes helpful but not absolutely necessary for reproduction and is maintained by the sex hormones in males and females. 703

second messenger Chemical signal such as cyclic AMP that causes the cell to respond to the first messenger—a hormone bound to a plasma membrane receptor. 684

secretory phase Phase of the uterine cycle in which increased production of progesterone causes the endometrium to double in thickness, producing a thick, mucoid secretion. 706

seed Mature ovule that contains an embryo with stored food enclosed in a protective coat. 362, 490

seedless vascular plant Land plants, such as lycophytes and ferns, which have vascular tissue but do not produce seeds. Reproduction involves flagellated sperm and production of windblown spores. 358

seed plant Land plant whose reproduction involves the production of seeds. Reproduction in seed plants is fully adapted to living on land because all reproductive structures are protected from drying out. Includes gymnosperms and angiosperms. 362

segmentation Repetition of body parts as segments along the length of the body; seen in annelids, arthropods, and chordates. 392

selective agent Environmental factor that affects the ability of an organism to survive and produce fertile offspring. 253

self-antigen Antigen that is produced by an organism. 615

semen (seminal fluid) (see-mun) Thick, whitish fluid consisting of sperm and secretions from several glands of the male reproductive tract. 702

semicircular canal (sem-ih-sur-kyuh-lur) One of three tubular structures within the inner ear that contain sensory receptors responsible for the sense of rotational equilibrium. 562

semiconservative replication Duplication of DNA resulting in two double helix molecules, each having one parental and one new strand. 196

semilunar valve (sem-ee-loo-nur) Valve resembling a half moon located between the ventricles and their attached vessels. 592

seminal vesicle (sem-uh-nul) Convoluted, saclike structure attached to the vas deferens near the base of the urinary bladder in males; adds secretions to semen. 702

seminiferous tubule (sem-uh-nif-ur-us) Long, coiled structure contained within chambers of the testis; where sperm are produced. 703

senescence Sum of the processes involving aging, decline, and eventual death of a plant or plant part. 473

sensation Conscious awareness of a stimulus due to a nerve impulse sent to the brain from a sensory receptor by way of sensory neurons. 551

sensory adaptation The phenomenon in which a sensation becomes less noticeable once it has been recognized by constant repeated stimulation. 551

sensory neuron Nerve cell that transmits nerve impulses to the central nervous system after a sensory receptor has been stimulated. 527

sensory receptor Structure that receives either external or internal environmental stimuli and is a part of a sensory neuron or transmits signals to a sensory neuron. 550

sepal Outermost, sterile, leaflike covering of the flower; usually green in color. 365, 491

Sertoli cell Type of cell in seminiferous tubules with FSH receptors; helps nourish and support developing sperm. 703

serum (seer-um) Light yellow liquid left after clotting of blood. 603

sessile Describes an animal that tends to stay in one place. 382

sex chromosome Chromosome that determines the sex of an individual; in humans, females have two

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X chromosomes, and males have an X and a Y chromosome. 144

sexually transmitted disease (STD) Illness communicated primarily or exclusively through sexual contact. 708

sexual reproduction Reproduction involving meiosis, gamete formation, and fertilization; produces offspring with chromosomes inherited from each parent with a unique combination of genes. 160, 700

shared ancestral trait In cladistics, a characteristic shared by both the outgroup and the ingroup that is judged to have preceded those of all the ingroup clades. 300

shared derived trait In cladistics, a characteristic that evolved after the ancestral trait and is present in an ancestor and all the members of a clade. 300

shoot system Aboveground portion of a plant consisting of the stem, leaves, and flowers. 432

short-day plant Plant that flowers when day length is shorter than a critical length (e.g., cocklebur, poinsettia, and chrysanthemum). 481

sieve-tube member Member that joins with others in the phloem tissue of plants as a means of transport for nutrient sap. 437, 452

signaling molecule Molecule that stimulates or inhibits an event in the cell cycle. 100

simple diffusion Movement of molecules or ions from a region of higher to lower concentration; it requires no energy and tends to lead to an equal distribution. 96

simple goiter (goy-tur) Condition in which an enlarged thyroid produces low levels of thyroxine. 689

simple muscle twitch Contraction of a whole muscle in response to a single stimulus. 580

single nucleotide polymorphism (SNP) Site present in at least 1% of the population at which individuals differ by a single nucleotide. These can be used as genetic markers to map unknown genes or traits. 259

sink In the pressure-flow model of phloem transport, the location (roots) from which sugar is constantly being removed. Sugar will flow to the roots from the source. 459

sink population Population that is found in an unfavorable area where at best the birthrate equals the death rate; sink populations receive new members from source populations. 810

sister chromatid One of two genetically identical chromosomal units that are the result of DNA replication and are attached to each other at the centromere. 144

skeletal muscle Striated, voluntary muscle tissue that comprises skeletal muscles; also called striated muscle. 512

skeletal system System of bones, cartilage, and ligaments that works with the muscular system to protect the body and provide support for locomotion and movement. 516

skin Outer covering of the body; can be called the integumentary system because it contains organs such as sense organs. 515

skull Bony framework of the head, composed of cranial bones and the bones of the face. 572

sliding filament model An explanation for muscle contraction based on the movement of actin filaments in relation to myosin filaments. 582

slime mold Protists that decompose dead material and feed on bacteria by phagocytosis; vegetative state is mobile and amoeboid. 342

small interfering RNAs (siRNA) Type of small RNA that combines with a complex and thereafter silences (inactivates) a chosen mRNA. 219

small intestine In vertebrates, the portion of the digestive tract that precedes the large intestine; in humans, consists of the duodenum, jejunum, and ileum. 634

small RNAs (sRNA) RNAs of limited length that function in various ways within the nucleus to regulate gene expression following transcription. 218

smooth ER (SER) Membranous system of tubules, vesicles, and sacs in eukaryotic cells; lacks attached ribosomes. 72

smooth muscle Nonstriated, involuntary muscle tissue found in the walls of internal organs. 512

sociobiology Application of evolutionary principles to the study of social behavior of animals, including humans. 750

sodium-potassium pump Carrier protein in the plasma membrane that moves sodium ions out of and potassium ions into cells; important in nerve and muscle cells. 98

soft palate (pal-it) Entirely muscular posterior portion of the roof of the mouth. 632

soil Accumulation of inorganic rock material and organic matter that is capable of supporting the growth of vegetation. 462

soil profile Vertical section of soil from the ground surface to the unaltered rock below. 462

solute Substance that is dissolved in a solvent, forming a solution. 34, 97

solution Fluid (the solvent) that contains a dissolved solid (the solute). 34

solvent Liquid portion of a solution that serves to dissolve a solute. 34, 97

somatic system That portion of the peripheral nervous system containing motor neurons that control skeletal muscles. 540

sorus (pl., sori) Dark spot on the underside of fern fronds that is a collection of spore-producing structures. 361

source In the pressure-flow model of phloem transport, the location (leaves) of sugar production. Sugar will flow from the leaves to the sink. 459

source population Population that can provide members to other populations of the species because it lives in a favorable area, and the birthrate is most likely higher than the death rate. 810

speciation Origin of new species due to the evolutionary process of descent with modification. 272

species Group of similarly constructed organisms capable of interbreeding and producing fertile offspring; organisms that share a common gene pool; the taxon at the lowest level of classification. 14, 296

species richness Number of species in a community. 769

specific epithet In the binominal system of taxonomy, the second part of an organism's name; it may be descriptive. 15

spermatogenesis (spur-mat-uh-jen-ih-sis) Production of sperm in males by the process of meiosis and maturation. 703

sphincter (sfingk-tur) Muscle that surrounds a tube and closes or opens the tube by contracting and relaxing. 617, 633

spinal cord Part of the central nervous system; the nerve cord that is continuous with the base of the brain plus the vertebral column that protects the nerve cord. 534

spinal nerve Nerve that arises from the spinal cord. 539

spindle apparatus Microtubule structure that brings about chromosome movement during nuclear division. 146

spleen Large, glandular organ located in the upper left region of the abdomen; stores and purifies blood. 611

spongy bone Porous bone found at the ends of long bones where red bone marrow is sometimes located. 576

spongy mesophyll Layer of tissue in a plant leaf containing loosely packed

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cells, increasing the amount of surface area for gas exchange. 438

sporangium (pl., sporangia) Structure that produces spores. 342, 357

spore Asexual reproductive or resting cell capable of developing into a new organism without fusion with another cell, in contrast to a gamete. 335, 354

sporophyte Diploid generation of the alternation of generations life cycle of a plant; produces haploid spores that develop into the haploid generation. 354, 490

squamous epithelium Type of epithelial tissue that contains flat cells. 509

S stage In the cell cycle, the period of time during which DNA replication occurs so that the chromosomes are duplicated. 145

stabilizing selection Outcome of natural selection in which extreme phenotypes are eliminated and the average phenotype is conserved. 264

stamen In flowering plants, the portion of the flower that consists of a filament and an anther containing pollen sacs where pollen is produced. 365, 491

starch Storage polysaccharide found in plants that is composed of glucose molecules joined in a linear fashion with few side chains. 48

statolith Sensors found in root cap cells that cause a plant to demonstrate gravitropism. 476

stem Usually the upright, vertical portion of a plant that transports substances to and from the leaves. 432

stereoscopic vision Vision characterized by depth perception and three-dimensionality. 413

steroid (steer-oyd) Type of lipid molecule having a complex of four carbon rings; examples are cholesterol, progesterone, and testosterone. 50

steroid hormone Type of hormone that has a complex of four carbon rings but different side chains from other steroid hormones. 684

stigma In flowering plants, portion of the pistil where pollen grains adhere and germinate before fertilization can occur. 365

stolon Stem that grows horizontally along the ground and may give rise to new plants where it contacts the soil—e.g., the runners of strawberry plants. 499

stoma (pl., stomata) Small opening between two guard cells on the underside of leaf epidermis through which gases pass. 107, 355, 436, 456

stratified As in the outer layer of skin, having several layers. 509

stratum (pl., strata) Ancient layer of sedimentary rock; results from slow deposition of silt, volcanic ash, and other materials. 251

stream Freshwater channel, smaller than a river. 791

striated Having bands; in cardiac and skeletal muscle, alternating light and dark crossbands produced by the distribution of contractile proteins. 512

strobilus Terminal cluster of specialized leaves that bear sporangia. 358

stroma Fluid within a chloroplast that contains enzymes involved in the synthesis of carbohydrates during photosynthesis. 107

structural gene Gene that codes for an enzyme in a metabolic pathway. 212

style Elongated, central portion of the pistil between the ovary and stigma. 365

subcutaneous layer A sheet that lies just beneath the skin and consists of loose connective and adipose tissue. 515

substrate Reactant in a reaction controlled by an enzyme. 90

substrate feeder Organism that lives in or on its food source. 628

substrate-level ATP synthesis Process in which ATP is formed by tranferring a phosphate from a metabolic substrate to ADP. 126

surface-area-to-volume ratio Ratio of a cell's outside area to its internal volume. 65

survivorship Probability of newborn individuals of a cohort surviving to particular ages. 730

sustainable development Management of an ecosystem so that it maintains itself while providing services to human beings. 811

sustainable society Interactive group of individuals who provide for their needs in a way that will allow future generations to enjoy the same standard of living. 800, 813

swallowing Muscular movement of the pharynx and esophagus to take the food bolus from the mouth to the stomach. 633

symbiosis Relationship that occurs when two different species live together in a unique way; it may be beneficial, neutral, or detrimental to one and/or the other species. 764

sympathetic division The part of the autonomic system that usually promotes activities associated with emergency (fight-or-flight) situations; uses norepinephrine as a neurotransmitter. 541

sympatric speciation Origin of new species in populations that overlap geographically. 279

synapse (sin-aps, si-naps) Junction between neurons consisting of the presynaptic (axon) membrane, the synaptic cleft, and the postsynaptic (usually dendrite) membrane. 530

synapsis (sih-nap-sis) Pairing of homologous chromosomes during prophase I of meiosis I. 155

synaptic cleft (sih-nap-tik) Small gap between presynaptic and postsynaptic membranes of a synapse. 530

syndrome Group of symptoms that appear together and tend to indicate the presence of a particular disorder. 163

synovial joint (sih-noh-vee-ul) Freely movable joint in which two bones are separated by a cavity. 577

syphilis (sif-uh-lis) Sexually transmitted disease caused by the bacterium *Treponema pallidum* that, if untreated, can lead to cardiac and central nervous system disorders. 708

systematics Study of the diversity of organisms to classify them and determine their evolutionary relationships. 296

systemic circuit Blood vessels that transport blood from the left ventricle and back to the right atrium of the heart. 593, 598

systemin In plants, an 18-amino-acid peptide that is produced by damaged or injured leaves and leads to the wound response. 483

systole (sis-tuh-lee) Contraction period of the heart during the cardiac cycle. 594

systolic pressure (sis-tahl-ik) Arterial blood pressure during the systolic phase of the cardiac cycle. 599

T

taiga Terrestrial biome that is a coniferous forest extending in a broad belt across northern Eurasia and North America. 786

tandem repeat Sequence of DNA nucleotides that is repeated many times in a row. 239

taste bud Sense organ containing the receptors associated with the sense of taste. 552

taxon Group of organisms that fills a particular classification category. 296

taxonomy Branch of biology concerned with identifying, describing, and naming organisms. 14, 296

T cell Lymphocyte that matures in the thymus. Cytotoxic T cells kill antigen-bearing cells outright; helper T cells

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release cytokines that stimulate other immune system cells. 601, 611

T cell receptor (TCR) Molecule on the surface of a T cell that can bind to a specific antigen fragment in combination with an MHC molecule. 616

temperate deciduous forest Forest found south of the taiga; characterized by deciduous trees such as oak, beech, and maple; moderate climate; relatively high rainfall; stratified plant growth; and plentiful ground life. 788

temperate grassland Grazing, fire, and drought restrict tree growth in this terrestrial biome. 788

temperate rain forest Coniferous forest—e.g., the forest running along the west coast of Canada and the United States—characterized by plentiful rainfall and rich soil. 786

template (tem-plit) Pattern or guide used to make copies; parental strand of DNA serves as a guide for the production of daughter DNA strands, and DNA also serves as a guide for the production of messenger RNA. 196

tendon Strap of fibrous connective tissue that connects skeletal muscle to bone. 511, 580

terminal bud Bud that develops at the apex of a shoot. 432

terminal bud scale scar Marking from the shedding of terminal bud scales; age of a stem can be determined by number of scars. 441

territoriality Marking and/or defending a particular area against invasion by another species member. 748

territory Area occupied and defended exclusively by an animal or group of animals; often used for the purpose of feeding, mating, and caring for young. 748

testcross Cross between an individual with the dominant phenotype and an individual with the recessive phenotype. The resulting phenotypic ratio indicates whether the dominant phenotype is homozygous or heterozygous. 176

test group Group that participates in an experiment and is exposed to the experimental variable. 5

testis (pl., testes) Male gonad that produces sperm and the male sex hormones. 700

testosterone (tes-tahs-tuh-rohn) Male sex hormone that helps maintain sexual organs and secondary sex characteristics. 703

tetrad Homologous chromosomes, each having sister chromatids that are joined during meiosis. 156

thalamus (thal-uh-mus) Part of the brain located in the lateral walls of the third ventricle that serves as the integrating center for sensory input; it plays a role in arousing the cerebral cortex. 536

theory of ecosystems Concept that organisms are members of populations that interact with each other and with the physical environment at a particular locale. 12

theory of evolution Concept that all living things have a common ancestor, but each is adapted to a particular way of life. 13

therapeutic cloning Used to create mature cells of various cell types. Also used to learn about specialization of cells and to provide cells and tissues for treating human illnesses. 230

thermoacidophile Type of archaean that lives in hot, acidic, aquatic habitats, such as hot springs or near hydrothermal vents. 325

thermoreceptor Sensory receptor that is sensitive to changes in temperature. 550

thigmotropism In plants, unequal growth due to contact with solid objects, as the coiling of tendrils around a pole. 476

threatened species Species that is likely to become endangered in the foreseeable future (e.g., bald eagle, gray wolf, Lousiana black bear). 800

threshold Electrical potential level (voltage) at which an action potential or nerve impulse is produced. 528

thrombin (thrahm-bin) Enzyme that converts fibrinogen to fibrin threads during blood clotting. 603

thylakoid Flattened sac within a granum whose membrane contains chlorophyll and where the light reactions of photosynthesis occur. 107, 324

thylakoid space Inner compartment of the thylakoid. 107

thymus gland Lymphatic organ, located along the trachea behind the sternum, involved in the maturation of T lymphocytes in the thymus gland. Secretes hormones called thymosins, which aid the maturation of T cells and perhaps stimulate immune cells in general. 611

thyroid gland Endocrine gland in the neck that produces several important hormones, including thyroxine, triiodothyronine, and calcitonin. 689

thyroid-stimulating hormone (TSH) Substance produced by the anterior pituitary that causes the thyroid to secrete thyroxine and triiodothyronine. 686

thyroxine (T_4) (thy-rahk-sin) Hormone secreted from the thyroid gland that promotes growth and development; in general, it increases the metabolic rate in cells. 689

tight junction Junction between animal cells that seals the cells to one another. 99

tissue Group of similar cells that perform a common function. 9, 508

tissue culture Process of growing tissue artificially, usually in a liquid medium in laboratory glassware. 500

tissue fluid Fluid that surrounds the body's cells; consists of dissolved substances that leave the blood capillaries by filtration and diffusion. 511, 602

tonsillitis Infection of the tonsils that causes inflammation and can spread to the middle ears. 632

tonsils Partially encapsulated lymph nodules located in the pharynx. 611

topography Surface features of the Earth. 783

torpedo stage Stage of development of a sporophyte embryo; embryo has a torpedo shape, and the root and shoot apical meristems are present. 496

totipotent Cell that has the full genetic potential of the organism, including the potential to develop into a complete organism. 500

touch receptor One of several cutaneous (skin) receptors that responds to light pressure. 558

toxin Substance produced by a bacterium that has a poisonous effect on the body and causes illness. 326

tracer Substance having an attached radioactive isotope that allows a researcher to track its whereabouts in a biological system. 28

trachea (tray-kee-uh) In birds and mammals, passageway that conveys air from the larynx to the bronchi; also called the windpipe. 654

tracheae In insects, air tubes located between the spiracles and the tracheoles. 591, 653

tracheid In flowering plants, type of cell in xylem that has tapered ends and pits through which water and minerals flow. 437, 452

tract Bundle of myelinated axons in the central nervous system. 534

transcription Process whereby a DNA strand serves as a template for the formation of mRNA. 198

transcription activator Protein that initiates transcription by RNA polymerase and thereby starts the process that results in gene expression. 213

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transcription factor In eukaryotes, protein required for the initiation of transcription by RNA polymerase. 213
transduction Exchange of DNA between bacteria by means of a bacteriophage. 322
trans fats Fats known to cause cardiovascular disease because they contain partially hydrogenated fatty acids. 49
transfer RNA (tRNA) Type of RNA that transfers a particular amino acid to a ribosome during protein synthesis; at one end, it binds to the amino acid, and at the other end it has an anticodon that binds to an mRNA codon. 200
transformation Taking up of extraneous genetic material from the environment by bacteria. 322
transitional fossil A fossil that bears a resemblance to two groups that in the present day are classified separately. 256
translation Process whereby ribosomes use the sequence of codons in mRNA to produce a polypeptide with a particular sequence of amino acids. 198
translation repressor protein In the cytoplasm, one of a number of proteins that prevent the translation of an mRNA. 220
translocation Movement of a chromosomal segment from one chromosome to another nonhomologous chromosome, leading to abnormalities (e.g., Down syndrome). 164, 202
transmission electron microscope Similar to the scanning electron microscope, but the image is colored by a computer. 66
transpiration Plant's loss of water to the atmosphere, mainly through evaporation at leaf stomata. 455
transport vesicle Vesicle formed in the ER that carries proteins and lipids to the Golgi apparatus. 72
transposon DNA sequence capable of randomly moving from one site to another in the genome. 240
trichocyst Found in ciliates; contains long, barbed threads useful for defense and capturing prey. 340
trichomes Outgrowth of the epidermis, such as a hair or a thorn. 444
trichomoniasis Sexually transmitted disease caused by the parasitic protozoan *Trichomonas vaginalis.* 708
triglyceride (trih-glis-uh-ryd) Neutral fat composed of glycerol and three fatty acids. 49, 640
triplet code Each sequence of three nucleotide bases in the DNA of genes stands for a particular amino acid. 198
triploid endosperm In flowering plants, nutritive storage tissue that is derived from an egg uniting with polar nuclei during double fertilization. 367
trisomy One more chromosome than usual. 162
trochophore larva Independent motile feeding stage in the development of the trochozoa; recognized by two bands of cilia around its middle. 387
trochozoa Type of protostome that produces a trochophore larva, which has two bands of cilia around its middle. 383
trophic level Feeding level of one or more populations in a food web. 773
trophoblast Outer cells of a blastocyst that help form the placenta and other extraembryonic membranes. 716
tropical rain forest Biome near the equator in South America, Africa, and the Indo-Malay regions; characterized by warm weather, plentiful rainfall, a diversity of species, and mainly tree-living animal life. 790
tropism In plants, a growth response toward or away from a directional stimulus. 446, 476
trypsin Protein-digesting enzyme secreted by the pancreas. 634
tuber Enlarged, short, fleshy underground stem—e.g., potato. 499
tubular reabsorption Movement of primarily nutrient molecules and water from the contents of the nephron into blood at the proximal convoluted tubule. 672
tubular secretion Movement of certain molecules from blood into the distal convoluted tubule of a nephron so that they are added to urine. 673
tumor (too-mur) Cells derived from a single mutated cell that has repeatedly undergone cell division; benign tumors remain at the site of origin, and malignant tumors metastasize. 153
tumor suppressor gene Gene that codes for a protein that ordinarily suppresses cell division; inactivity can lead to a tumor. 222
tunicate Type of primitive invertebrate chordate. 398
turgor movement In plant cells, pressure of the cell contents against the cell wall when the central vacuole is full. 478
Turner syndrome Condition caused by the inheritance of a single X chromosome. 163
tympanic membrane (tim-pan-ik) Located between the outer and middle ear where it receives sound waves; also called the eardrum. 559
typhlosole Expanded dorsal surface of the long intestine of earthworms, allowing additional surface for absorption. 630

U

umbilical cord Cord connecting the fetus to the placenta through which blood vessels pass. 717
uniformitarianism Belief espoused by James Hutton that geological forces act at a continuous, uniform rate. 251
unique noncoding DNA DNA that does not code for a protein and whose unknown function may be different from that of other noncoding DNA. 240
unpacking Prior to transcription, the transformation of heterochromatin to euchromatin. 215
unsaturated fatty acid Fatty acid molecule that has one or more double bonds between the atoms of its carbon chain. 49
upwelling Upward movement of deep, nutrient-rich water along coasts; it replaces surface waters that move away from shore when the direction of prevailing winds shifts. 784
urea Main nitrogenous waste of terrestrial amphibians and most mammals. 666
uremia High level of urea nitrogen in the blood. 676
ureter (yoor-uh-tur) One of two tubes that take urine from the kidneys to the urinary bladder. 670
urethra (yoo-ree-thruh) Tubular structure that receives urine from the bladder and carries it to the outside of the body. 670
uric acid Main nitrogenous waste of insects, reptiles, and birds. 666
urinary bladder Organ where urine is stored before being discharged by way of the urethra. 670
urinary system Organ system consisting of the kidneys and urinary bladder; rids the body of nitrogenous wastes and helps regulate the water-salt balance of the blood. 517
urine Liquid waste product made by the nephrons of the vertebrate kidney through the processes of glomerular filtration, tubular reabsorption, and tubular secretion. 670
uterine cycle (yoo-tur-in, -tuh-ryn) Monthly occurring changes in the characteristics of the uterine lining (endometrium). 706
uterus (yoo-tur-us) Organ located in the female pelvis where the fetus develops; also called the womb. 704

utricle (yoo-trih-kul) Saclike cavity in the vestibule of the inner ear that contains sensory receptors for gravitational equilibrium. 563

V

vaccine Antigens prepared in such a way that they can promote active immunity without causing disease. 326, 615

vacuole Membrane-bounded sac, larger than a vesicle; usually functions in storage and can contain a variety of substances. In plants, the central vacuole fills much of the interior of the cell. 74

vagina Organ that leads from the uterus to the vestibule and serves as the birth canal and organ of sexual intercourse in females. 704

valence shell Outer shell of an atom. 28

valve Membranous extension of a vessel of the heart wall that opens and closes, ensuring one-way flow. 595

vascular cylinder In dicot roots, a core of tissues bounded by the endodermis, consisting of vascular tissues and pericycle. 438

vascular plants Land plants that have xylem and phloem. Xylem transports water and helps support an erect stem. 358

vascular tissue Transport tissue in plants consisting of xylem and phloem. 436

vas deferens (vas def-ur-unz, -uh-renz) Tube that leads from the epididymis to the urethra in males. 702

vegetative reproduction In seed plants, reproduction by means other than by seeds; in other organisms, reproduction by vegetative spores, fragmentation, or division of the somatic body. 499

vector (vek-tur) In genetic engineering, a means to transfer foreign genetic material into a cell (e.g., a plasmid). 232

vein Vessel that takes blood to the heart from venules; characteristically has nonelastic walls. 592

vena cava Large systemic vein that returns blood to the right atrium of the heart in tetrapods; either the superior or inferior vena cava. 598

ventilation Process of moving air into and out of the lungs; also called breathing. 650

ventricle (ven-trih-kul) Cavity in an organ, such as a lower chamber of the heart or the ventricles of the brain. 534, 592

venule (ven-yool, veen-) Vessel that takes blood from capillaries to a vein. 595

vermiform appendix Small, tubular appendage that extends outward from the cecum of the large intestine. 636

vertebrae Series of bones that enclose and protect the dorsal nerve cord. 399, 573

vertebral column (vur-tuh-brul) Series of joined vertebrae that extends from the skull to the pelvis. 573

vertebrate Chordate in which the notochord is replaced by a vertebral column. 384

vessel element Cell that joins with others to form a major conducting tube found in xylem. 437, 452

vestibule (ves-tuh-byool) Space or cavity at the entrance of a canal, such as the cavity that lies between the semicircular canals and the cochlea. 559

vestigial structure Remains of a structure that was functional in some ancestor but is no longer functional in the present-day organism. 257

villus (pl., villi) (vil-us) Small, fingerlike projection of the inner small intestinal wall. 635

viroids Naked strands of RNA that cause diseases in plants by directing the plant cell to produce more viroids. 315

visual accommodation Ability of the eye to focus at different distances by changing the curvature of the lens. 555

vitamin Essential requirement in the diet, needed in small amounts. Vitamins are often part of coenzymes. 91, 642

vocal cord Fold of tissue within the larynx; creates vocal sounds when it vibrates. 654

vulva External genitals of the female that surround the opening of the vagina. 704

W

waggle dance Figure-eight dance performed by honeybees to indicate locations of nectar sources. 753

water column In plants, water molecules joined together in xylem from the leaves to the roots. 454

water molds Filamentous organisms having cell walls made of cellulose; typically decomposers of dead freshwater organisms, but some are parasites of aquatic or terrestrial organisms. 342

water vascular system Series of canals that takes water to the tube feet of an echinoderm, allowing them to expand. 393

wax Sticky, solid, waterproof lipid consisting of many long-chain fatty acids usually linked to long-chain alcohols. 50

white blood cell (WBC) Leukocyte, of which there are several types, each having a specific function in protecting the body from invasion by foreign substances and organisms. 511, 601

white matter Myelinated axons in the central nervous system. 534

wood Secondary xylem that builds up year after year in woody plants and becomes the annual rings. 442

X

xenotransplantation Use of animal organs, instead of human organs, in human transplant patients. 236

xylem Vascular tissue that transports water and mineral solutes upward through the plant body; it contains vessel elements and tracheids. 358, 437, 452

xylem sap Solution of inorganic nutrients moved from a plant's roots to its shoots through xylem tissue. 452

Y

yeast Unicellular fungus that has a single nucleus and reproduces asexually by budding or fission, or sexually through spore formation. 372

yolk Dense nutrient material in the egg of a bird or reptile. 700

yolk sac Extraembryonic membrane that encloses the yolk of birds; in humans, it is the first site of blood cell formation. 715

Z

zone of cell division In plants, the part of the young root that includes the root apical meristem and the cells just posterior to it; cells in this zone divide every 12–36 hours. 440

zone of elongation In plants, the part of the young root that lies just posterior to the zone of cell division; cells in this zone elongate, causing the root to lengthen. 441

zone of maturation In plants, the part of the root that lies posterior to the zone of elongation; cells in this zone differentiate into specific cell types. 441

zooplankton Part of plankton containing protozoans and other types of microscopic animals. 339, 793

zoospore A motile spore. 342

zygospore Thick-walled resting cell formed during sexual reproduction of zygospore fungi; meiosis and spore formation occur upon germination. 372

zygote (zy-goht) Diploid cell formed by the union of sperm and egg; the product of fertilization. 155

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